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CCGS Hudson Expedition 2018-041: high-resolution investigation of deep-water seabed seeps and landslides along the Scotian Slope, offshore Nova Scotia, May 26 – June 15, 2018

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Publications in this series have not been edited; they are released as submitted by the author.

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Several staff contributed content to this expedition report (P. Fraser, K. Jarrett, A. Robertson, T. Fralic, and J. Webb). Robbie Bennett reviewed this report.

- Calvin Campbell and Alexandre Normandeau

1. BACKGROUND AND OBJECTIVES

The 2018041 CCGS Hudson expedition (Figure 1) was a joint mission between the Geological Survey of Canada (Atlantic) and the Nova Scotia Department of Energy and Mines (NSDEM). The expedition also included participants from the University of Calgary and St. Mary's University (Table 1). Past expeditions (2015018 and 2016011-PH2) on the Scotian Slope led to evidence of cold seeps on the seafloor and the presence of gas hydrates. The objectives of expedition 2018041 were to target several sites on the Scotian Slope with the purpose of collecting high resolution seabed imagery using an Autonomous Underwater Vehicle (AUV), hull-mounted (bathymetry, sub-bottom profiles) and towed instruments (sparker, video, photos), and sediment samples (gravity cores, box cores) in order to better understand cold seep and sediment transport processes (Table 2, Table 3, Table 4). Specifically:

1. Conduct high resolution bathymetry, sidescan, sub-bottom surveys by AUV over features identified during previous expeditions.

2. Collect high resolution video and photography at locations where seabed seepage of fluids is occurring..

3. Collect high resolution sparker reflection data.

4. Collect long (up to 9 m) gravity core and box core samples over a variety of targets. The sampling is aimed at collecting cores and grab samples that will be assessed for geochemistry, geomicrobiology, sedimentology and geotechnical parameters.

5. Deploy Unmanned Aerial Vehicle (UAV) from the vessel as a proof of concept for future field operations.

2. PARTICIPANTS

Table 1: Participants of the CGS Hudson expedition 2018-041

First Name	Last Name	Affiliation	Role
Calvin	Campbell	NRCan	Chief Scientist
Alex	Normandeau	NRCan	2nd Scientist
Desmond	Manning	NRCan	Technician
Patrick	Meslin	NRCan	Technician
Tom	Carson	NRCan	Technician
Angus	Robertson	NRCan	Technician
Kate	Jarrett	NRCan	Curation
Paul	Fraser	NRCan	GIS and Navigation
Eric	Patton	NRCan	GIS
Makeala	MacIntyre	NRCan	Sample processing
Katherine	MacCaull	NRCan	Student assistant
Alex	Whitney	NRCan	Student assistant
Tom	Fralic	Geoforce	Huntec operator
Tim	Murphy	DRDC	AUV lead
Owen	Shuttleworth	DRDC	AUV operations
Dan	Graham	DRDC	AUV operations
Jacob	Marshall	DRDC	AUV operations
Daniel	Gittens	Ucalgary	Geomicrobiology
Michelle	Wong	Ucalgary	Geomicrobiology
Gretta	Elizondo	Ucalgary	Geomicrobiology
Scott	Wang	Ucalgary	Geomicrobiology
Jamie	Webb	APT	Geochemistry
Jeremey	Bentley	SMU	Geochemistry

3. SUMMARY OF ACTIVITIES

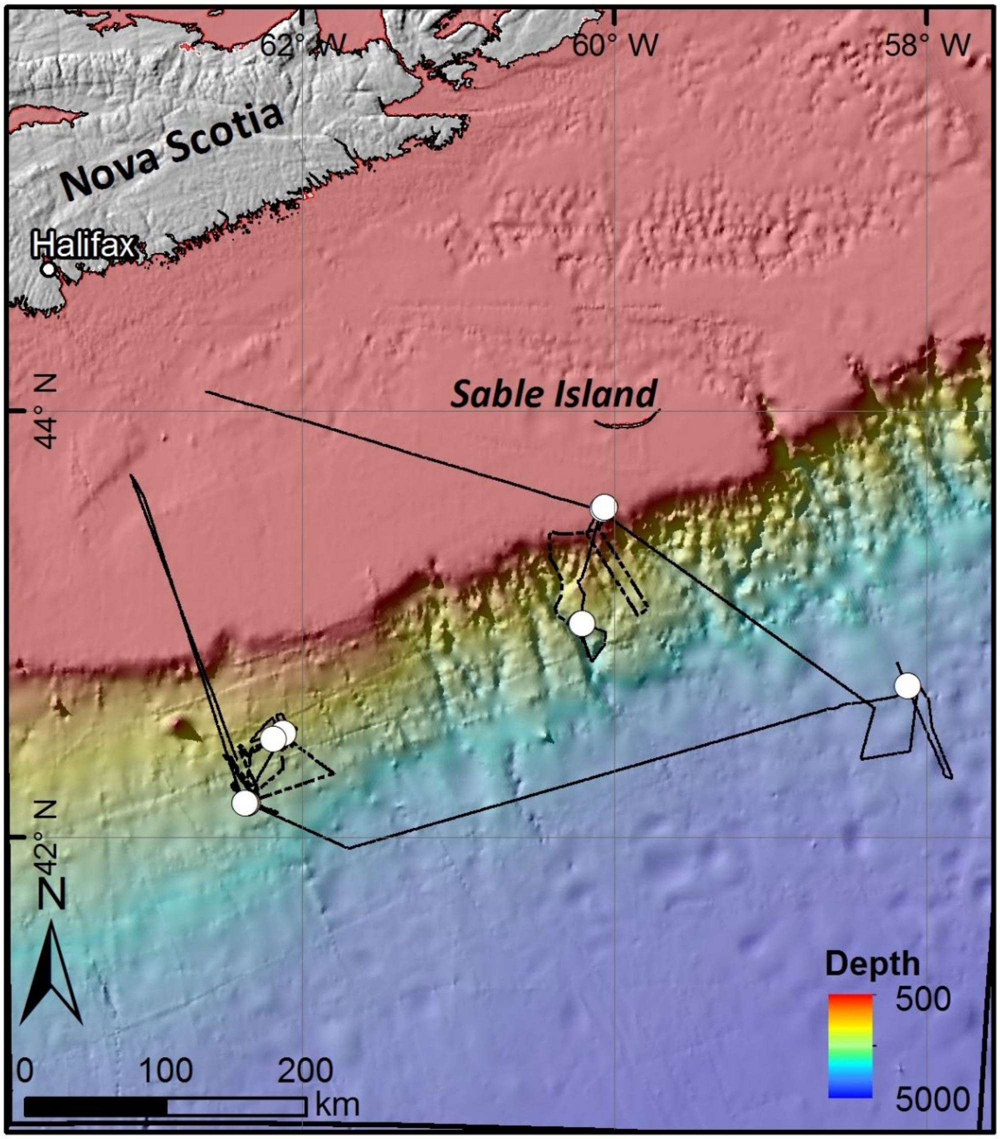

Figure 1: Navigation lines and station locations of 2018041 cruise.

Table 2: Summary of activities

Date	JD	Location	Activity	Gravity core	Box core	AUV	Huntec DTS	3.5 kHz	Camera	Notes
26/05/2018	146	Bedford Basin	AUV tests							
27/05/2018	147	Bedford Basin	AUV tests							
28/05/2018	148	Transit	Transiting					X		
29/05/2018	149	Head of Logan Canyon	Coring operations for Holocene geohazards	2				X		Issues with Huntec
30/05/2018	150	SW of Logan Canyon	Box coring for geomicrobiology		3		X	X		
31/05/2018	151	SW of Logan Canyon	Gravity coring and camera transects for seeps	2		X	X	X	1	Ballasted the AUV
01/06/2018	152	Head of Logan Canyon	AUV and box cores		1	X	X			AUV test in shallow water
02/06/2018	153	Head of Logan Canyon	AUV			X				AUV dive at the head of Logan Canyon
03/06/2018	154	The Gully	Seismic					X		Seismic stratigraphy of sediment waves
04/06/2018	155	The Gully	Coring	1				X		
05/06/2018	156	Transit	Transiting						1	
06/06/2018	157	South of Mohican Canyon	Camera and coring	2			X		1	
07/06/2018	158	AUV site 2A	AUV			X	X			Found the coring locations for the following day based on AUV
08/06/2018	159	Scotian Shelf	Transit					X		Personal emergencies resulted in transiting towards Halifax
09/06/2018	160	Mohican Canyon	Coring and camera	2				X	1	Aimed the AUV seep
10/06/2018	161	Mohican Canyon	AUV			X				
11/06/2018	162	Mohican Canyon	Coring and camera	1				X	2	Seep-related

Date	JD	Location	Activity	Gravity core	Box core	AUV	Huntec DTS	3.5 kHz	Camera	Notes
										clams?
12/06/2018	163	Mohican Channel	Coring	3			X			
13/06/2018	164	Transit	Transit					X		

Table 3: Core sample details.

Expedition	Station Number	Latitude	Longitude	Water Depth (m)	Core Type	Core Length (cm)	Comments
2018041	0001	43.553903	-60.06706	526	Gravity	392	Stratified acoustic target, core to be split and processed at GSC Atlantic, in the water 1245, going down 1316 (pengo winch issue on the way down), on the btm 13:27:46, at surface 13:40:11, 2 barrels, apparent penetration 609cm, catcher put back in the base of AB, gas cracking 55cm at base of core.
2018041	0002	43.548796	-60.07575	419	Gravity	433	Stratified acoustic target, core to be split and processed at GSC Atlantic, in the water 16:29:38, going down 1644, on the btm 16:49:14, at surface 17:04:18, 3 barrels, apparent penetration 884cm, 15cm catcher/cutter in split liner, gas cracking 80cm at base of core.
2018041	0003	43.009261	-60.20955	2362	Box Core	15	Stratified acoustic target, in water 11:19:04, on bottom 12:25:13, at surface 13:12:29, no water on top of box core and estimated 15cm sediment recovered, fine to med sand on surface, red brown mud over slightly stiffer grey mud, surface subsampled by U Calgary and SMU.

Expedition	Station Number	Latitude	Longitude	Water Depth (m)	Core Type	Core Length (cm)	Comments
2018041	0004	43.01075	-60.21491	2362	Box Core	25	Stratified acoustic target, in water 15:11:59, on bottom 16:15:08, at surface 17:07:49, not sure if hit the bottom so re-lowered, no water on top of sediment and estimated 25cm sediment recovered, red brown mud over slightly stiffer grey mud, 5x4x4cm angular finely laminated siltstone cobble, surface subsampled by U Calgary and SMU.
2018041	0005	43.007293	-60.21348	2408	Box Core	25	Smooth incoherent acoustic target, acoustic wipeout due to the presence of gas, in water 18:10:26, on bottom 19:07:49, at surface 20:00:31, no water on top of sediment and estimated 25cm sediment recovered, red brown mud over slightly stiffer grey mud, surface subsampled by U Calgary and SMU.
2018041	0006	43.00733	-60.21366	2408	Gravity	486.5	Smooth incoherent acoustic target, acoustic wipeout due to the presence of gas, core split and processed at sea, in the water 10:40:19, on the btm 11:46:21, at surface 12:44:47, 2 barrels, apparent pentration 609cm, 20.5cm catcher/cutter, 3.5cm tip, issues with the winch depth, A'A'' 5cm whole round, AA' 7cm whole round.

Expedition	Station Number	Latitude	Longitude	Water Depth (m)	Core Type	Core Length (cm)	Comments
2018041	0007	43.010485	-60.2117	2405	Gravity	43	Smooth stratified acoustic target, duplicate of 2016011Phase2 0041pc, core split and processed at sea, in the water 14:17:40, on the btm 15:17:37, at surface 16:11, 2 barrels, apparent pentration 366cm, issues with the winch depth and not sure if hit the bottom, recovered gas hydrate, 6cm at base directly subsampled out of the whole core as unable to take whole round.
2018041	0009	43.553768	-60.06701	526	Box Core	23	Smooth stratified acoustic target, in water 18:18:52, on bottom 18:34:23, at surface 18:46:52, 3rd attempt to hit the bottom successful, no water on top of sloping sediment surface, estimated 25cm sediment recovered, sandy at the base, two push cores taken for GSCA to be processed at GSCA, surface subsampled by U Calgary and SMU.
2018041	0010	42.7168	-58.12163	4228	Gravity	692.5	Smooth stratified acoustic target, core to be split and processed at GSC Atlantic, in the water 15:59:34, going down 16:05:40, on the btm 17:40:58, at surface 19:26:35, 3 barrels, still a discrepancy on the meter block and depth, apparent penetration 610cm, sediment in the butterfly valve at the top of the core, 12cm catcher/cutter in split liner, CC' 2cm bagged, DD' 3cm in end caps, FF' 7cm in end caps.

Expedition	Station Number	Latitude	Longitude	Water Depth (m)	Core Type	Core Length (cm)	Comments
2018041	0013	42.162286	-62.35568	2791	Gravity	629	Smooth stratified acoustic target, core split and processed at sea, going down 13:10:23, on the btm 14:08:30, 3 barrels, apparent penetration estimated 945 as mud on the head, clearly a mud line 1' above second barrel, 21cm catcher/cutter, A'A'' 5cm whole round, AA' 7cm whole round.
2018041	0014	42.159826	-62.3628	2782	Gravity	577.5	Rough incoherent acoustic target, core split and processed at sea, in the water 16:39:15, going down 16:52:09, on the btm 17:46:10, at the surface 18:55:17, 3 barrels, apparent penetration 914cm, A'A'' 5cm whole round, AA' 7cm whole round.
2018041	0015	42.162406	-62.37383	2730	Gravity	629	Smooth incoherent acoustic target, core split and processed at sea, in the water 09:44:52, going down 09:58:56, on the btm 10:53:27, at the surface 11:54:26, 3 barrels, apparent penetration 914cm, A'A'' 5cm whole round, AA' 7cm whole round, catcher/cutter 23cm in split liner, tip 3cm bagged.
2018041	0017	42.161888	-62.37332	2742	Gravity	603	Smooth incoherent acoustic target, core split and processed at sea, in the water 16:48:22, on the btm 17:59:10, at the surface 19:00:09, issues with the Pengo winch, 3 barrels, apparent penetration 914cm, A'A'' 5cm whole round, AA' 7cm whole round, catcher/cutter 23cm in split liner, tip 2cm bagged.

Expedition	Station Number	Latitude	Longitude	Water Depth (m)	Core Type	Core Length (cm)	Comments
2018041	0019	42.162113	-62.37355	2745	Gravity	595.5	Smooth incoherent acoustic target, core split and processed at sea, in the water 13:16:13, on the btm 14:14:29, at the surface 15:15:22, 3 barrels, apparent penetration 914cm, A'A'' 5cm whole round, AA' 7cm whole round, catcher/cutter 22.5cm in split liner.
2018041	0021	42.494195	-62.12642	2079	Gravity	739	Rough incoherent acoustic target, core split and processed at sea, in the water 09:47:41, on the btm 10:32:08, at the surface 11:18:29, 3 barrels, apparent penetration 853cm, A'A'' 5cm whole round, AA' 9cm whole round, catcher/cutter lost on recovery.
2018041	0022	42.492181	-62.12893	2083	Gravity	512	Rough incoherent acoustic target, core split and processed at sea, in the water 12:49:16, on the btm 13:42:12, at the surface 14:45:23, 3 barrels, apparent penetration 792cm, A'A'' 5cm whole round, AA' 9cm whole round, catcher/cutter 18cm and tip 10cm in split liner.
2018041	0023	42.466221	-62.19236	2154	Gravity	377	Rough incoherent acoustic target, core split and processed at sea, on the btm 17:20:04, at the surface 18:17:14, 3 barrels, apparent penetration 609cm, A'A'' 5cm whole round, AA' 5cm whole round, catcher/cutter 17cm in split liner.

Table 4: 4K Camera station details.

Expedition	Station Number	Latitude	Longitude	Comments
2018041	0008	43.003305	-60.209432	Smooth stratified acoustic target, GSCA 4K camera, in the water 19:10:13, used the winch room geographic location for the images, 80 images in total and 49 good images of the seafloor.
2018041	0011	42.156346	-62.360938	Smooth incoherent acoustic target wipeout due to gas, GSCA 4K camera, at the surface 21:21:41, lost contact with the pinger, lost the weight and camera system hit the bottom, used the winch room geographic location for the images, 375 images in total and 26 good images of the seafloor.
2018041	0012	42.162991	-62.374697	Smooth incoherent acoustic target wipeout due to gas, GSCA 4K camera, in the water 10:13, at the surface 12:15:06, used the winch room geographic location for the images, 93 images in total and 34 good images of the seafloor.
2018041	0016	42.158513	-62.359092	Smooth incoherent acoustic target, GSCA 4K camera, in the water 13:56:33, at the surface 16:20:41, used the winch room geographic location for the images, 58 images in total and 24 good images of the seafloor.
2018041	0018	42.154124	-62.384538	Smooth incoherent acoustic target, GSCA 4K camera, in the water 09:29:35, at the surface 12:25:35, repositioning the Hudson during the station, used the winch room geographic location for the images, 54 images in total and 35 good images of the seafloor.
2018041	0020	42.147548	-62.380195	Smooth incoherent acoustic target, GSCA 4K camera, in the water 17:29:45, at the surface 20:05:56, repositioning the Hudson during the station, used the winch room geographic location for the images, 49 images in total and 35 good images of the seafloor.

4. PRELIMINARY RESULTS

4.1 Cruise statistics

During the expedition, 920 line-km of Huntec DTS sparker and 2170 line-km of Knudsen 3.5 kHz sub-bottom profiler data were collected. In addition, 3 AUV surveys were conducted and23 stations were completed consisting of 13 Gravity Cores, 6 Camera Transects, 4 Box Cores.

4.2 Key preliminary results

1. The expedition used a multi-parameter approach to assessing seabed seepage of gas and fluids. Sampling locations were first selected from data collected previously (e.g. from other mission on CCGS Hudson in 2015 and 2016, multichannel seismic reflection data from industry that images deep into the subsurface and surface-acquired multibeam bathymetry). The general areas were then surveyed with high resolution sub-bottom profilers, AUV (bathymetry sidescan and sub-bottom profiler) to reveal in very high-resolution seafloor features. These features were subsequently sampled and photographed.

2. A number of technical achievements were made during the expedition. The large gravity corer worked well and provided a very efficient means to collect core samples. Deployment and recovery protocols for the AUV were improved with each AUV dive. The shipborne areal drone proved feasible and will likely be a useful tool in the future for identification of sea-surface slicks.

3. The AUV data provide unprecedented imagery of the seabed and shallow sub-surface. At the first AUV survey location at the head of Logan Canyon, numerous small gullies and pockmarks show active seabed processes in that area. At the second location, a 450 m long fissure at the flank of a salt diaper likely provides strong evidence for fluid seepage. At the third site, the sub-bottom data show that many shallow faults terminate in a shallow mass transport deposit, and acoustic amplitudes seem to show that the deposits form good seals for upward migrating fluids. Additional results from the AUV surveys are given in Appendix 2.

5. DAILY NARRATIVE

All times in Atlantic Daylight Time

JD146 – Saturday May 26, 2018 – Depart to Bedford Basin

After completion of mobilization, we departed the Bedford Institute of Oceanography at 1630 and sailed out into Bedford Basin. There was insufficient daylight to begin sea trials, so we stayed in the basin for the night.

JD147 – Sunday May 27, 2018 – Bedford Basin

We began testing handling procedures with the coring equipment at 0600. A fault was identified with the AUV at 0930. The fault was repaired by 1700; however, a cooling issue was discovered with one of the sample refrigerators in the late afternoon so it was decided to spend the night in Bedford Basin so that the AUV test deployment could be conducted and the fridge container could be repaired in the morning.

JD148 – Monday May 28, 2018 – Transit to Logan Canyon

The Fast Rescue Craft (FRC) picked up the refrigerator technician at 0700 and the repair was completed by 0830. We conducted a test deployment and recovery of the AUV at 0800 which was successfully completed by 1000. The vessel departed Halifax at 1030 and began transiting towards the first work area at the head of Logan Canyon. We began logging the 3.5 and 12 kHz sounders at 1500. We slowed down at around midnight to run survey pattern over head of Logan Canyon. Seas picked up overnight.

JD149 – Tuesday May 29, 2018 – Head of Logan Canyon

Chirp sub-bottom profiles were collected over the Logan Canyon Head until 0600. The crew then prepared to deploy the AUV and the FRC for ballast testing. The AUV was ready to deploy at 0800. The FRC was deployed first and upon navigating around the ship, it was decided that the swell was too big (1-2 m) to deploy safely the AUV. The FRC was brought back on board before lunch. At 0945, a gravity core, with 2 3-m barrels was deployed and hit bottom at 1027 (0001GC). It was back at the surface at 1040. Core 0001GC consisted of 2 ½ sections. At 1330, a second gravity core with 3 3-m barrels was deployed and hit bottom at 1350 (0002GC). It was back at the surface at 1405 and recovered 2 ½ sections as well. Following the recovery of the gravity core, we started transiting towards area 41 for geophysical surveys. At 1730, the Huntec was deployed but was not functioning. 3.5 kHz sub-bottom profiles were collected instead while the Huntec was being worked on. It was repaired at 2130 but it was decided to wait until the next survey night to deploy. 3.5 kHz sub-bottom profiles were collected over the night (Figure 2).

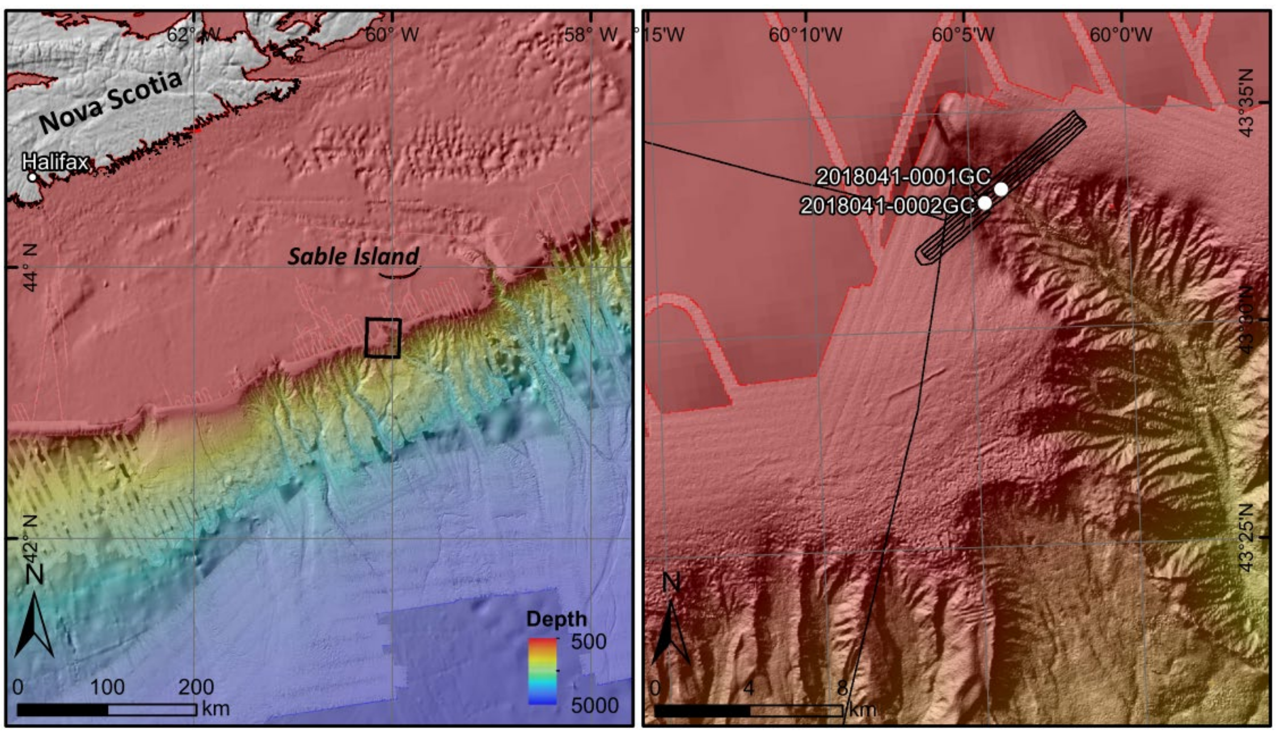

Figure 2: Summary of Julian Day 149 at the head of Logan Canyon. Black lines are seismic surveys (3.5 kHz) and white dots are cores collected.

JD150 – Wednesday May 30, 2018 – Near Bonnecamps Canyon

Chirp sub-bottom profiles were collected until 0700. Weather conditions did not permit the use of the gravity corer (2-3 m waves). At 0820, the crew deployed the box corer and hit the bottom at 0925 (0003BC) at site of interest for NSDEM. It was recovered at 1015. No evidence of oil or gas was observed. We transited a few hundred metres towards another site and deployed the box corer at 1210.

It hit bottom at 1315 (0004BC) and was recovered at 1415. These two sites (0003 and 0004) were selected based on data collected in 2015 and 2016 and the 3.5 kHz sub-bottom profiler data collected during the 2018 expedition showed some evidence of possible fluid/gas in the shallow sub-surface. The third site of the day (0005BC) was selected based on a large wipeout in the newly-acquired ship-based 3.5 kHz data. The box corer was deployed at 1510 and hit bottom at 1610. The three box cores were sampled for geochemistry and geomicrobiology. Box coring operations terminated at 1730. The Huntec was then deployed successfully and we began seismic surveys in the same area as the previous day, but aiming at targets observed in the newly-acquired data surveying in a grid pattern (Figure 3).

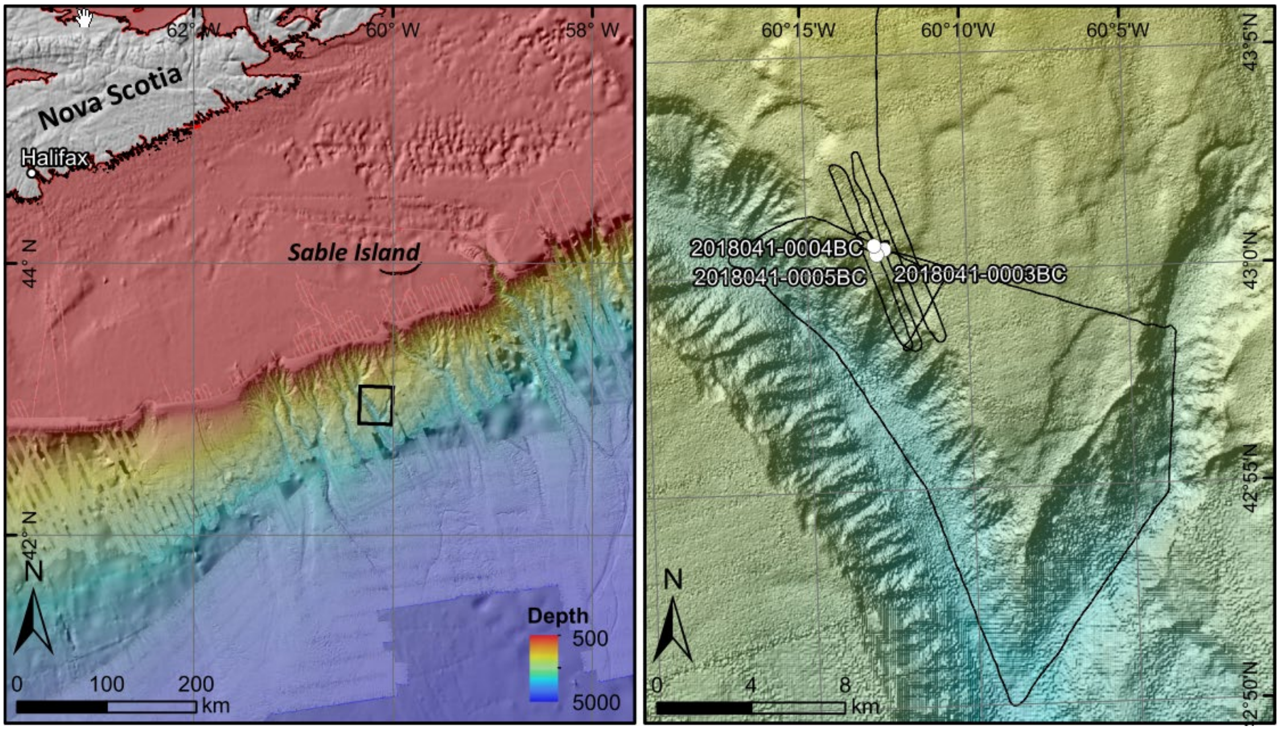

Figure 3: Summary of Julian Day 150. Black lines are seismic surveys (3.5 kHz) and white dots are cores collected.

JD151 – Thursday May 31, 2018 – Near Bonnecamps Canyon

Huntec profiles were collected until 0700. The first gravity core (0006GC) was ready to deploy at 0740 and hit bottom at 0845. It targeted the same site as the gas hydrate site from 2016011-PH2, but a mistake on the bridge led to the ship going to the wrong site. Fortunately, that site was close to the second site that was proposed for the day. The gravity core was recovered at 0945. A second gravity core (0007GC), this time at the location of gas hydrates was deployed at 1115 and hit bottom at 1215. The sub-bottom over this site consists of parallel high-amplitude reflections. Following the recovery of the core, a camera transect was done along the coring sites 0003-0004-0007. The camera was deployed at 1615 and was recovered at 1800. Of a total of 80 photos collected, 49 were of the seabed which mostly shows bioturbated mud with sparse gravel and cobbles. The Huntec was then deployed for an overnight survey up a canyon thalweg towards the head of Logan Canyon (Figure 4).

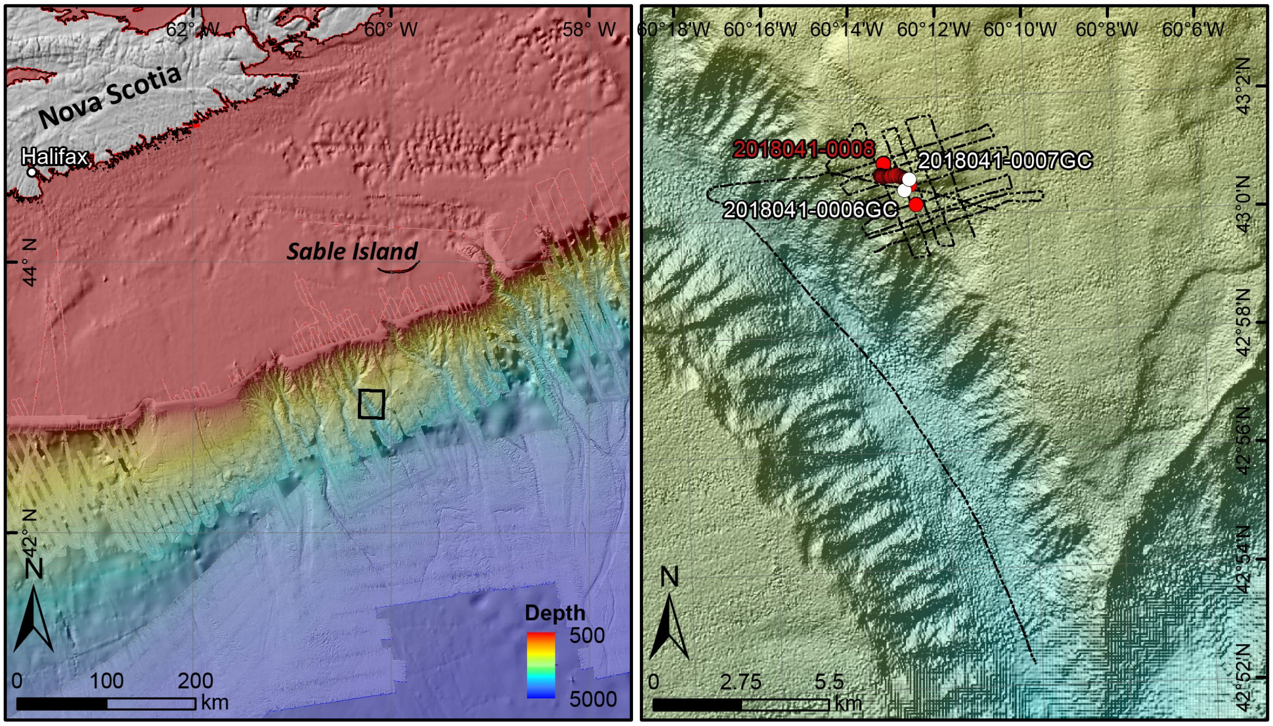

Figure 4: Summary of Julian Day 151. Dotted black lines are seismic surveys (Huntec), red dots are bottom photographs and white dots are cores collected.

JD152 – Friday June 1, 2018 – Head of Logan Canyon

We recovered the Huntec fish at 0600 and moved into position to deploy the AUV. The AUV was in the water by 0730. Weather conditions were excellent. The AUV conducted a "loiter test" for approximately 2 hours, then surfaced. After surfacing, the AUV attempted to dive to conduct the first survey. Shortly after diving, a tilt fault alarm went off on the AUV and it surfaced automatically. It was determined that there was likely an issue with the ballast as the AUV was not able to dive subsequent to the fault. The FRC and Zodiac were deployed in order to attempt to ballast the AUV while it was in the water. Approximately 22 kg of additional ballast was added but was insufficient to adjust the trim of the AUV. The AUV was recovered at 1400. Once on deck, it was discovered that the emergency drop ballast had somehow been lost during the dive leading to the issue. AUV operations were aborted for the day. We steamed to the thalweg of Logan canyon and collected a box core (STN 009) which was at the same location as STN 001. Upon recovery of the box core, we deployed the Huntec DTS (Figure 5).

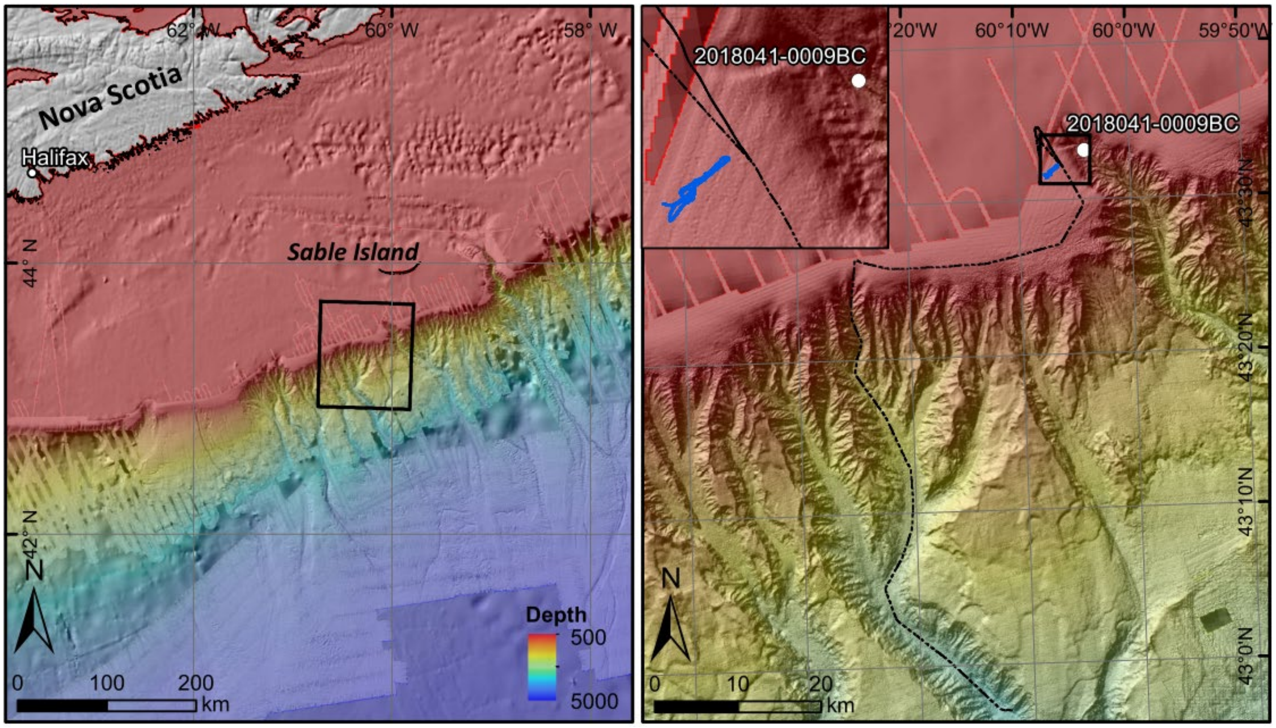

Figure 5: Summary of Julian Day 152. Dotted black lines are seismic surveys (Huntec), blues lines are AUV lines and white dots are cores collected.

JD153 – Saturday June 2, 2018 – Head of Logan Canyon

We recovered the Huntec at 0600 near the head of Logan Canyon. We deployed the AUV at 0700. The conditions were calm but foggy. AUV began to conduct first survey at the head of Logan Canyon but returned a fault early in the survey. The AUV returned to the start of the survey then conducted the survey. The ship followed the AUV during the 3 hour transit so that communication could be maintained. The AUV surfaced at 1130 and was recovered by 1300. AUV data shows great promise and an incredible improvement in resolution over the surface acquired data. Gale warning was issued at 1000. The captain requested moving to deeper water where the seas would build less. At 1400 we began to transit to the lower part of the Gully, running 3.5 kHz the entire way. Vessel heave corrections from the IMU were configured for the Knudsen 3.5 kHz system, much improving data quality. Winds picked up to 35 kts overnight (Figure 6).

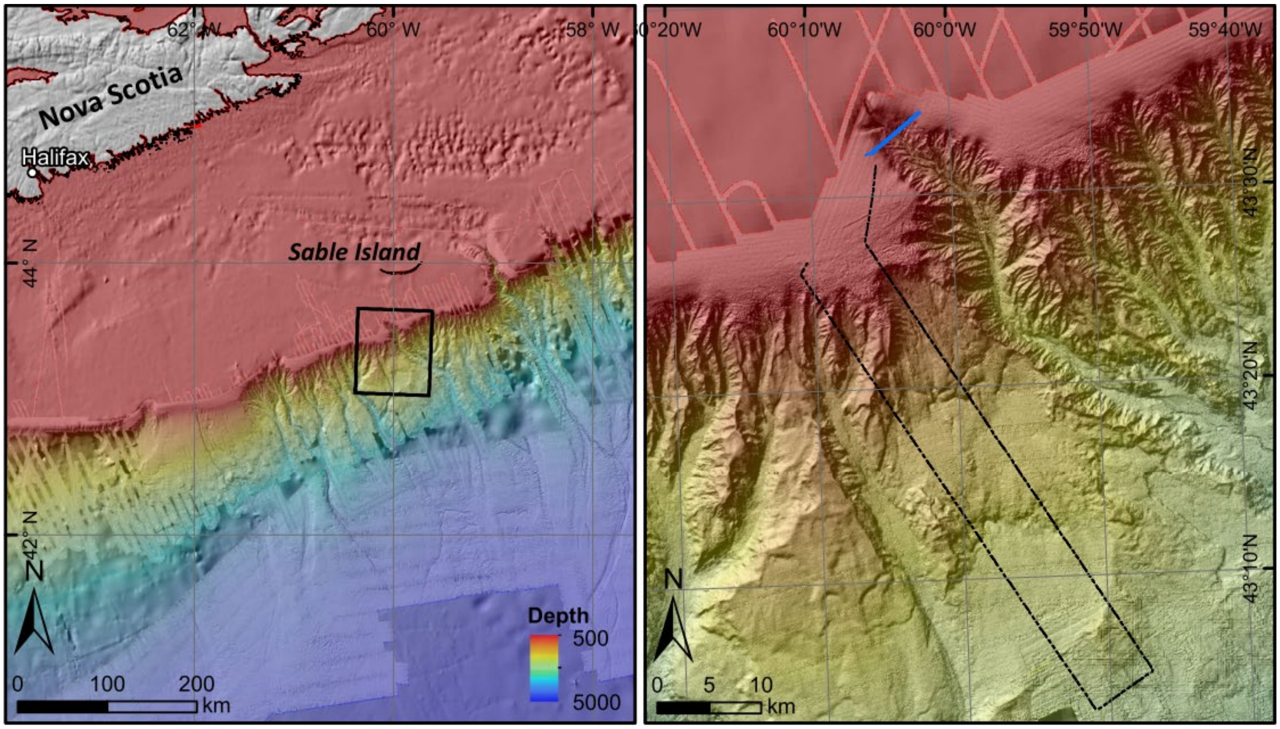

Figure 6: Summary of Julian Day 153. Dotted black lines are seismic surveys (Huntec) and blues lines are AUV lines.

JD154 – Sunday June 3, 2018 – Distal part of The Gully

We had to slow down overnight because of weather. Winds were gusting to 45 kts with steady 35 kts. Seas built throughout the day to 6 m. We ran N-S lines on standby while waiting for the weather to clear. The Knudsen sounder was run the entire time and gave variable data quality (Figure 7).

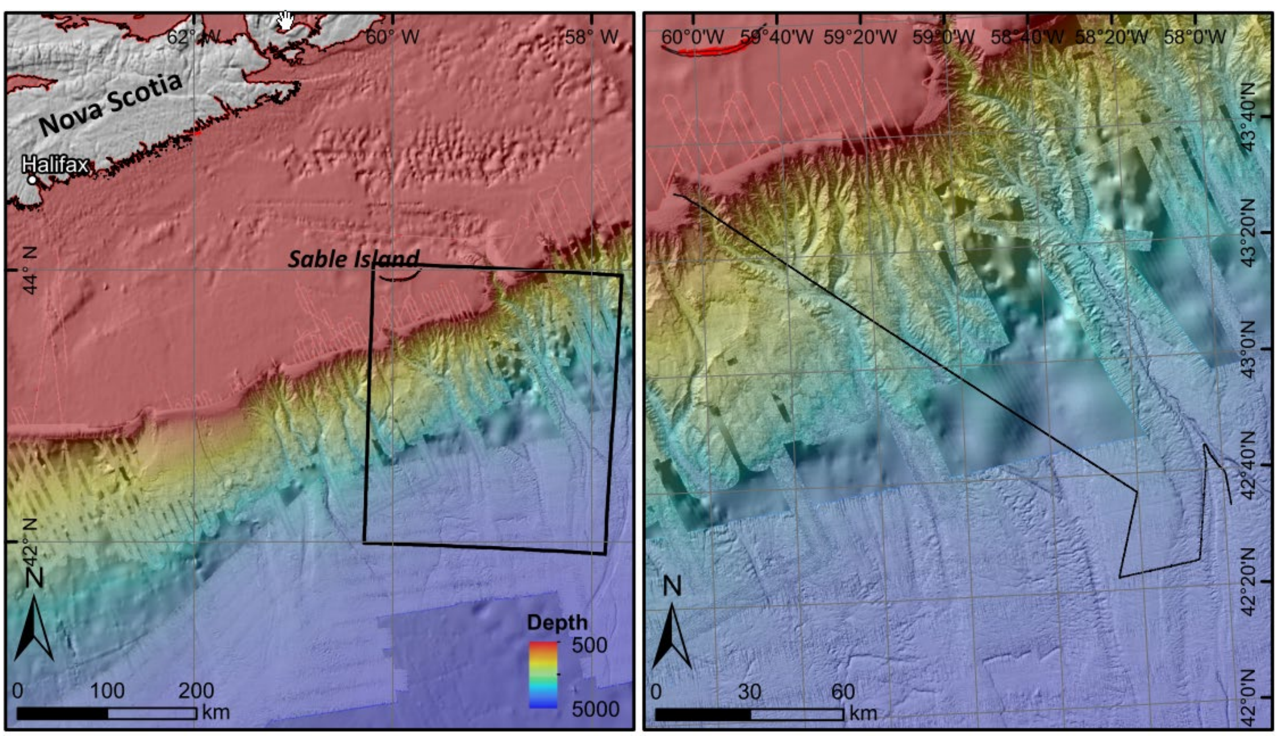

Figure 7: Summary of Julian Day 154. Black lines are seismic surveys (3.5 kHz).

JD155 – Monday June 4, 2018 – Distal part of The Gully

We arrived at a potential site at 0600 but the swell was significant and winds were still 30 kts gusting to 45. The winds started to die down later in the morning and by 1300 conditions were sufficient to core. We conducted a gravity core (STN 010) on the western levee of the lower part of The Gully. We then transited west towards the lower Mohican Channel area (Figure 8).

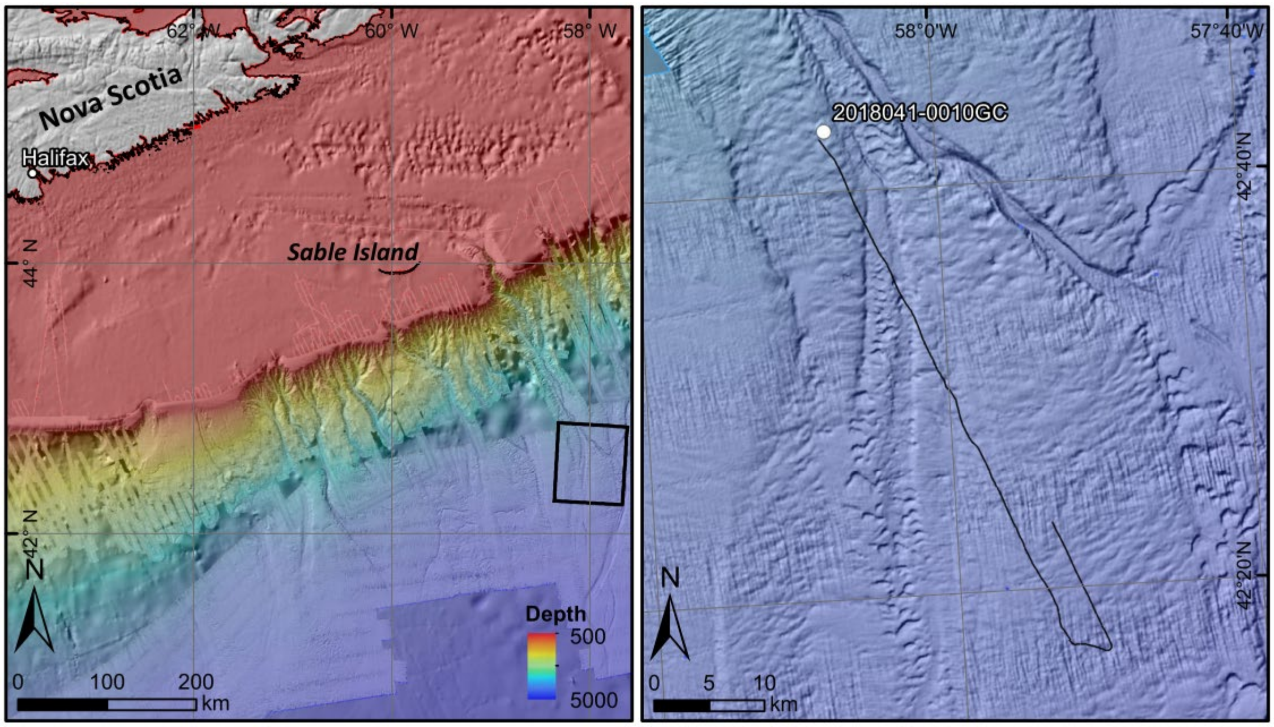

Figure 8: Summary of Julian Day 155. Black lines are seismic surveys (3.5 kHz) and white dots are cores.

JD156 – Tuesday June 5, 2018– Transit to Mohican Channel area

Winds picked up overnight. Another gale warning was issued, but weather looked better for later in the week. Winds dropped off by late morning, but significant swell remained. The swell reduced by 1600 and we were able to conduct a camera station (STN 011). After the camera station, we deployed the Huntec DTS and ran survey lines in a NW-SE direction overnight (Figure 9).

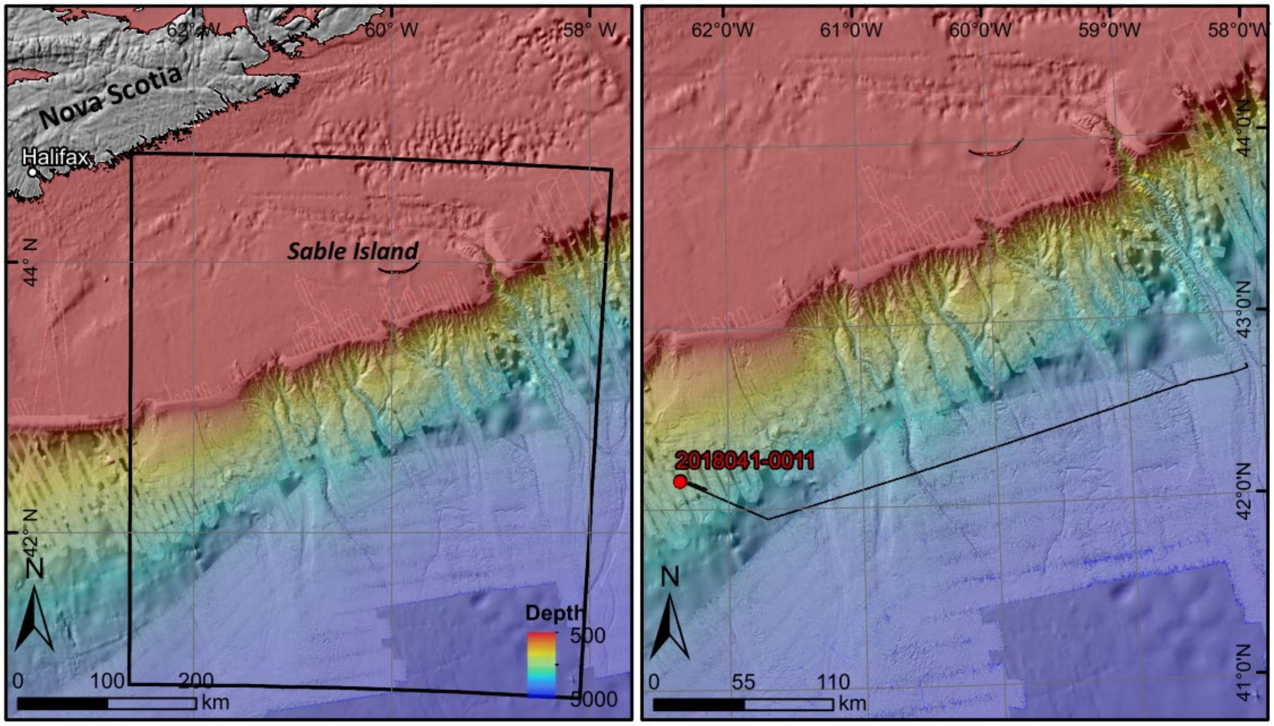

Figure 9: Summary of Julian Day 156. Black lines are seismic surveys (3.5 kHz) and red dot is a camera station.

JD157 – Wednesday June 6, 2018 – Mohican Channel area

We recovered the Huntec at 0630. Significant swell of 3-4 metres remained from the previous system that went through, so we conducted a camera station (STN 012) over some potential seep targets. After the camera stations, conditions improved enough that we could core. We conducted two gravity cores (STN 013 and 014) at two prioritized seep sites (NSDEM sites 02A -01 and 02). No obvious signs of gas in the core samples. We deployed the Huntec at 1700 and ran lines to identify more core targets (Figure 10).

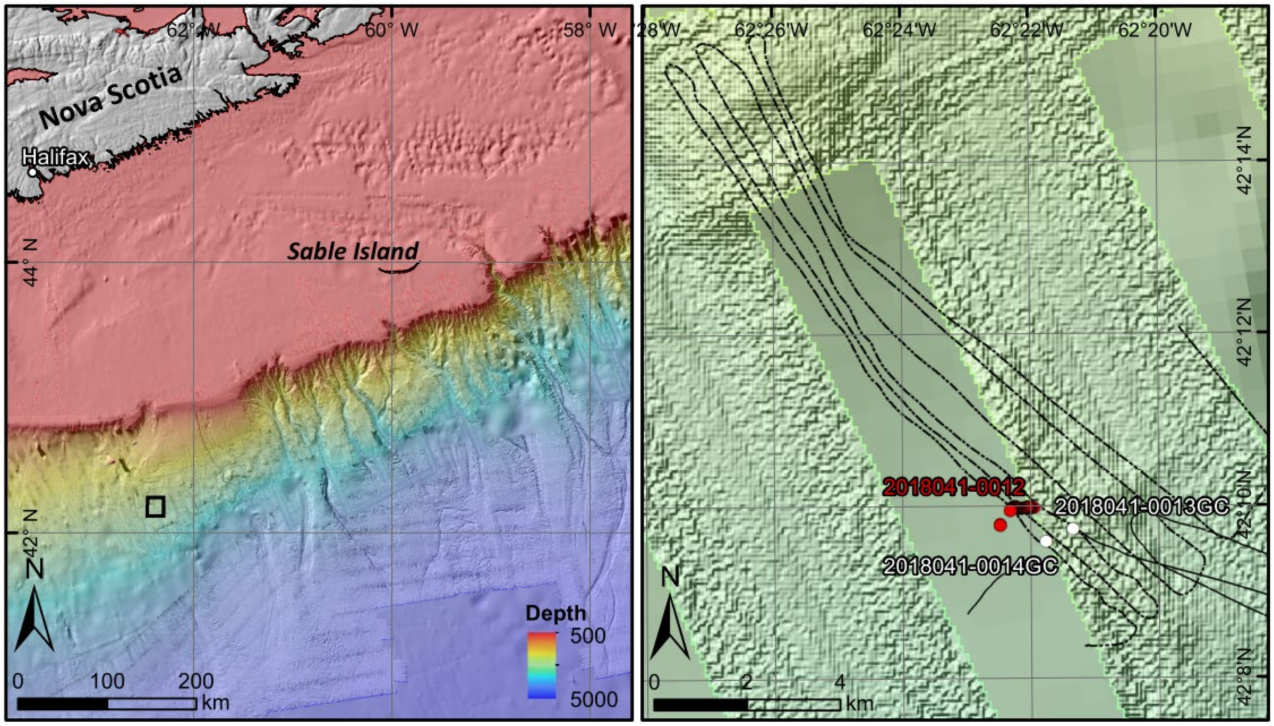

Figure 10: Summary of Julian Day 157. Black dotted lines are seismic surveys (Huntec), white dots are sediment cores and red dot is a camera station.

JD158 – Thursday June 7, 2018 – Mohican Channel area

We recovered the Huntec DTS at 0600. We deployed the AUV at 0700 in 10-15 kt winds. AUV dived to loiter depth (~300m) for loiter. A "fin" fault was encountered with 10 minutes left to go on the 2 hr loiter. AUV surfaced and fault was corrected. The AUV was sent to dive and conduct survey. The AUV completed survey and surfaced by 1545. The AUV was recovered and all personnel on deck by 1700. Huntec DTS was deployed at 1715. The AUV data show mostly featureless seabed except for an ellipse-shaped fissure about 450 by 50 m in size. The sub-bottom data show extensive faulting and acoustic wipe-outs associated with the fissure (Figure 11).

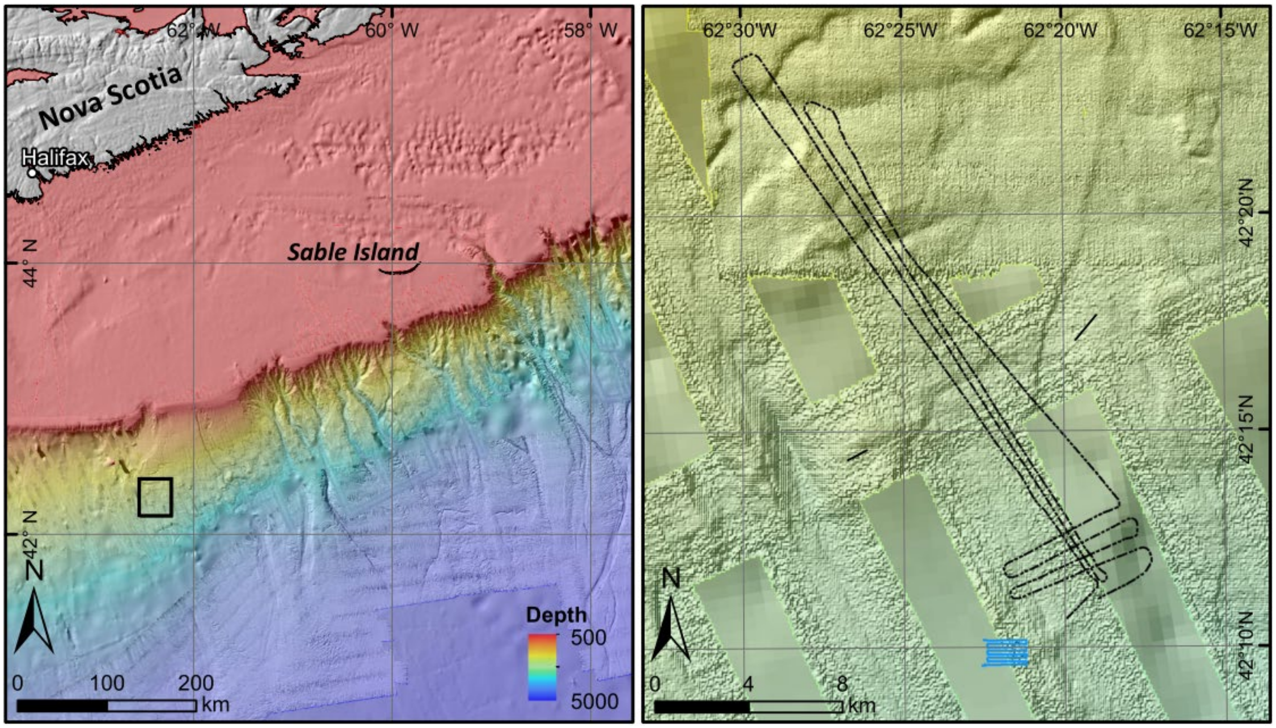

Figure 11: Summary of Julian Day 158. Black dotted lines are seismic surveys (Huntec) and blue lines are AUV surveys.

JD159 – Friday June 8, 2018 – Mohican Channel area

We recovered the Huntec at 0600. We began steaming towards Halifax to disembark a science staff member for a family emergency. We transferred the staff member to CCGS Sir William Alexander near Emerald Basin at 1400 and began steaming back to the work site. We arrived back in the study area at 2300 and ran a grid of 3.5 kHz lines overnight (Figure 12).

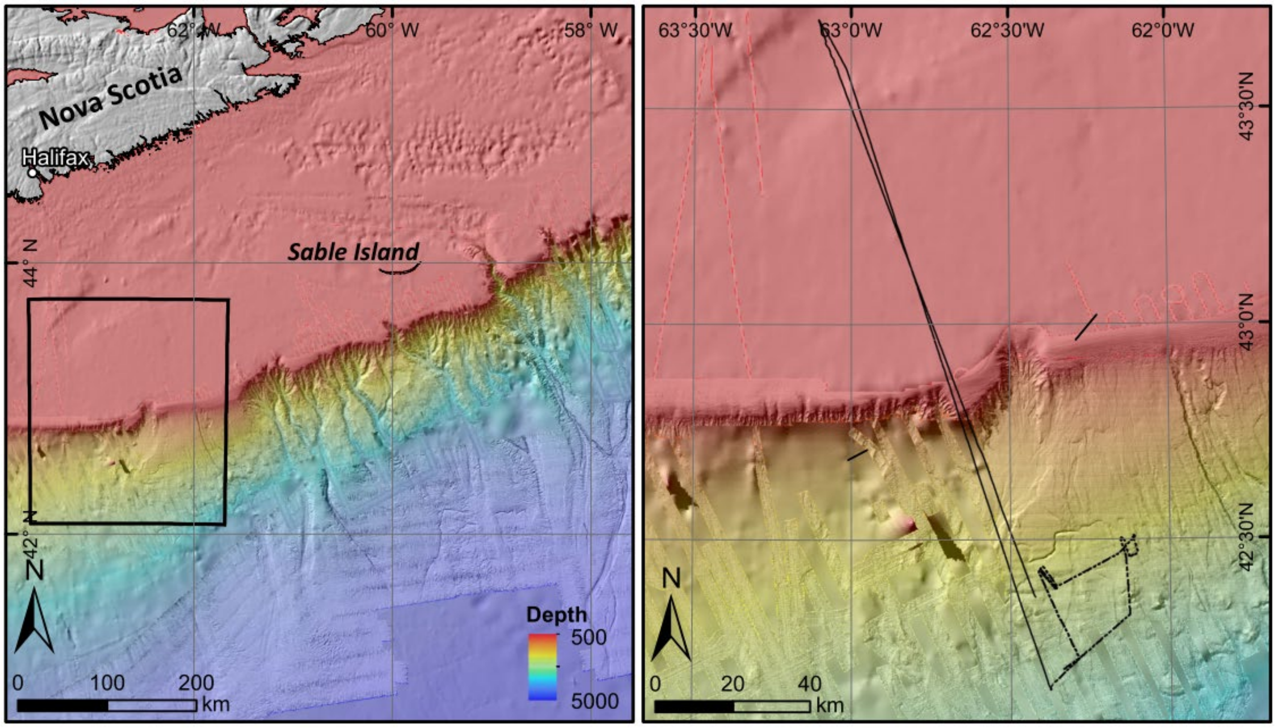

Figure 12: Summary of Julian Day 159. Black lines are seismic surveys (3.5 kHz) and black dotted lines are Huntec surveys.

JD160 – Saturday June 9, 2018 – Mohican Channel area

At 0500, we ran a tight grid of lines over the fissure feature in order to refine its position. We took a core (STN015) which recovered normal looking mud and no obvious signs of gas. Station keeping was excellent and the TrackPoint indicated the corer position was ~50 m north of the ship. The Pengo winch developed an oil leak from the gear box during recovery. We conducted camera STN 016 across the fissure. Drift direction changed during the transect and TrackPoint data indicate that the camera may not have made it to the feature. We conducted gravity core STN 017 in the afternoon, offsetting from the morning position by 50 m. Once again, the core recovered muddy sediment with no sign of gas. We deployed the Huntec DTS at 1730 (Figure 13).

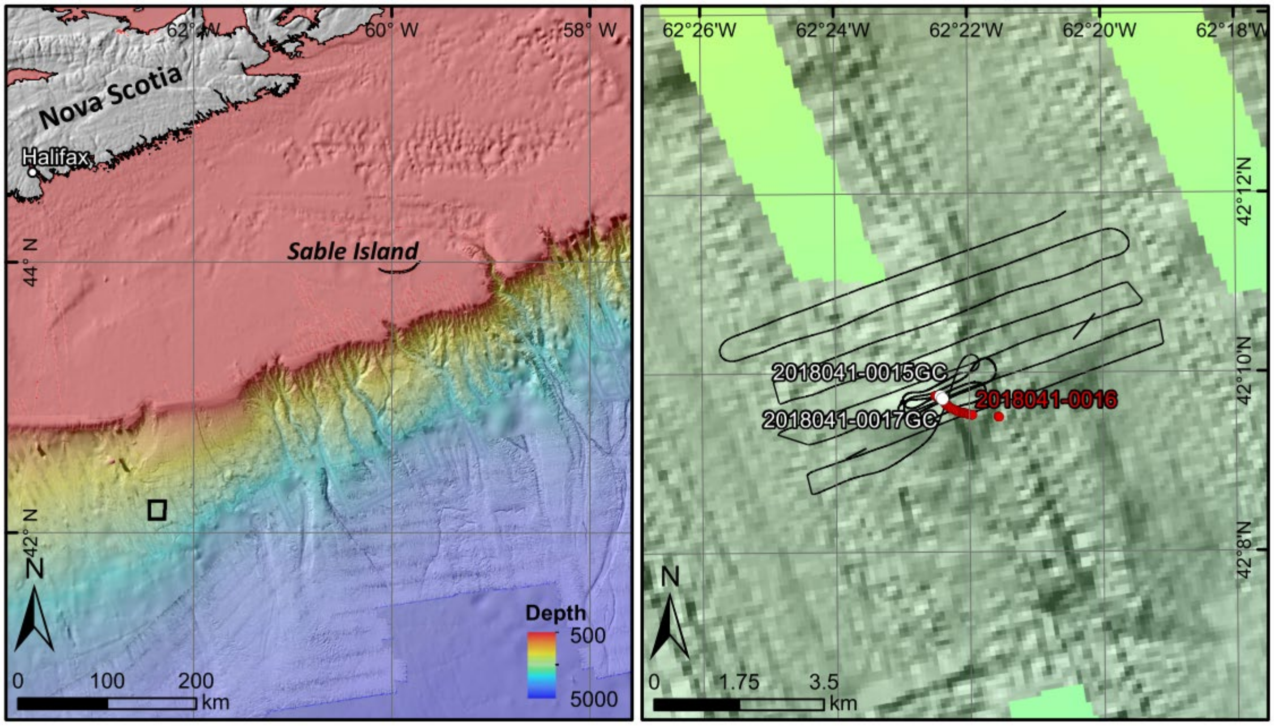

Figure 13: Summary of Julian Day 160. Black lines are seismic surveys (3.5 kHz), white dots are sediment cores and red dots are a camera station.

JD161 – Sunday June 10, 2018 – Mohican Channel area

We recovered the Huntec at 0600 and moved to location for AUV deployment. At 0650, the Captain decided conditions were fine for deployment. Winds picked up to 15 kts later in the morning. AUV had issues after the loiter and surfaced ~2 km from the start of the survey area. Survey dive began at 1100. AUV completed survey at 1600 and was back on deck by 1715. We transited towards the fissure area and ran the Knudsen over the area in a grid. The AUV sub-bottom data revealed interbedded acoustically stratified sediments and mass transport deposits. Abundant faults with amplitude anomalies in the shallow subsurface are present. The swath bathymetry from the AUV shows scour like features, possibly formed by pockmarks which subsequently failed downslope, giving the seabed an almost vuggy appearance (Figure 14).

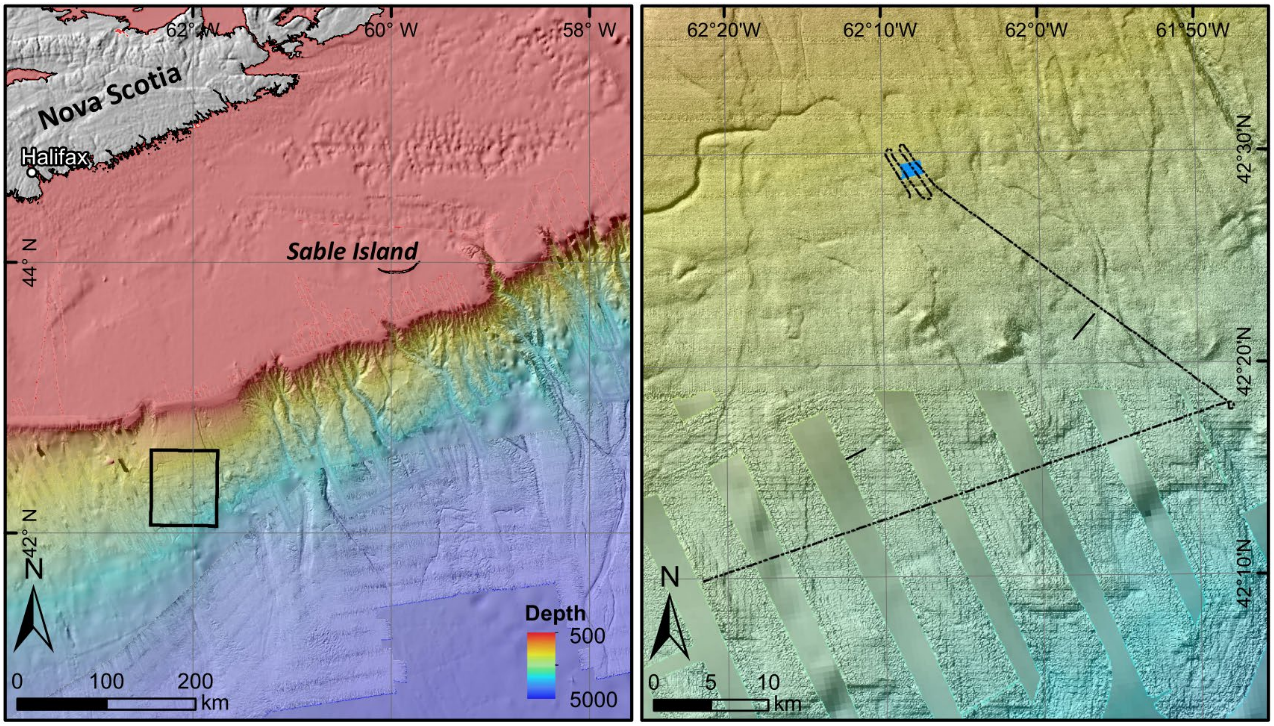

Figure 14: Summary of Julian Day 161. Black dotted lines are seismic surveys (Huntec) and blue lines are AUV surveys.

JD162 – Monday June 11, 2018 – Mohican Channel area

We began our camera transect over the fissure at 0620 (STN 018). The ship was asked to reposition twice during the drift based on the information from the TrackPoint. We completed the camera transect at 1015. Some of the photos showed abundant white clam shells and "shelly friable hash" layer at the surface, as well as several burrow-like holes, possibly fluid escape features. We took a gravity core in the fissure (STN 019). Core recovered normal looking, sticky sediments. We conducted a second camera station in the afternoon (STN 020). We deployed the Huntec DTS at 1730 (Figure 15).

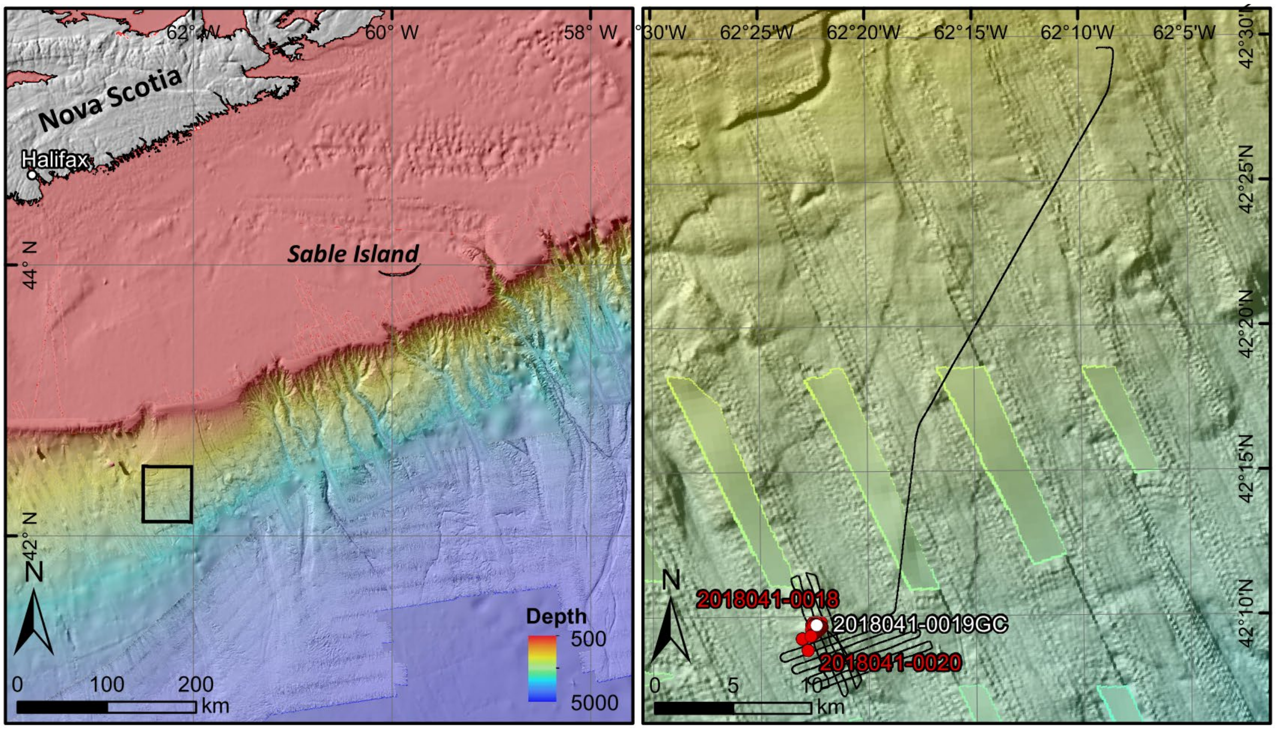

Figure 15: Summary of Julian Day 162. Black lines are seismic surveys (3.5 kHz), white dots are sediment cores and red dots are a camera station.

JD163 – Tuesday June 12, 2018 – Mohican Channel area

We recovered the Huntec DTS at 0600 and steamed to first core site. STN 021 targeted some chimney wipeouts that were overlain by a 3 m thick MTD. The second core (STN 022) target a small debris-filled gully that is formed where a deep-seated fault comes near the surface. The last core (STN 023) targeted a thicker MTD that was underlain by abundant wipeouts and appeared gas-charged. Winds picked up during the day to 20 kts from south. The Pengo winch had some minor issues during the day (a small oil leak at the gearbox and some alignment issues). We started running the Knudsen at 1630 overnight (Figure 16).

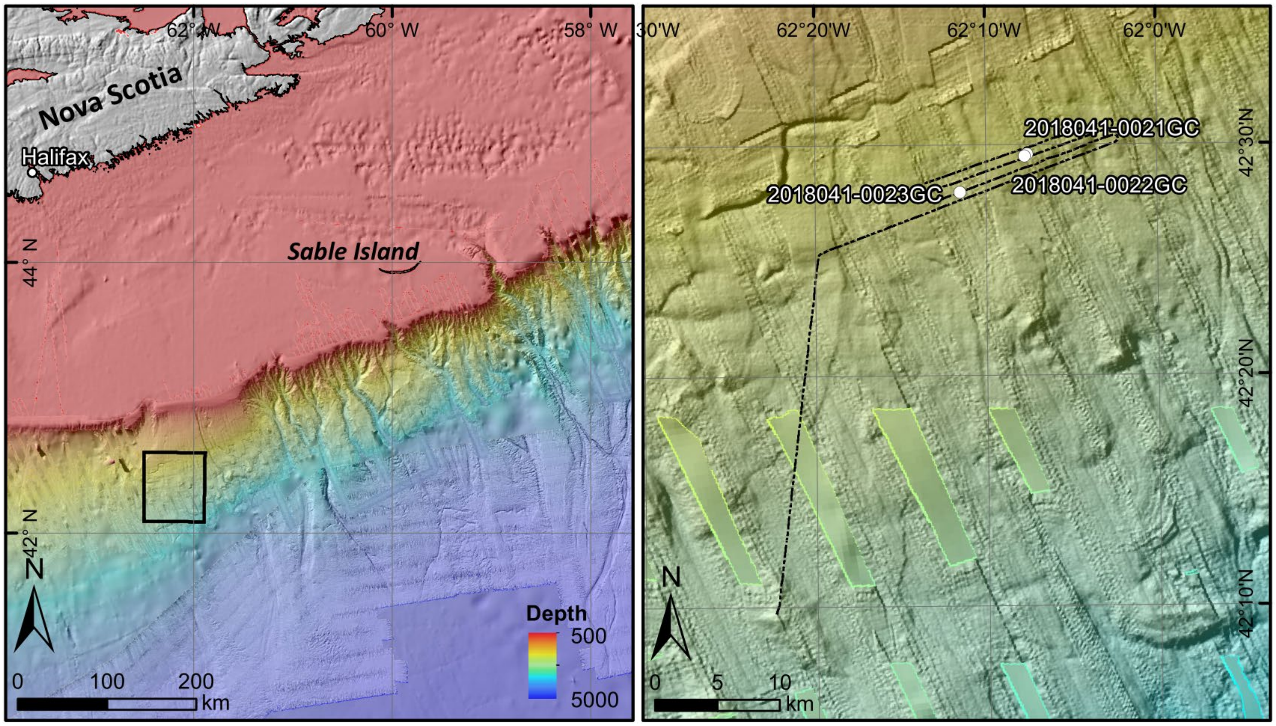

Figure 16- Summary of Julian Day 163. Black lines are seismic surveys (3.5 kHz) and white dots are sediment cores.

JD164 – Wednesday June 13, 2018 – Transit to BIO

Winds remained high overnight and a significant swell persisted making it impossible to sample. We waited until noon to make a decision whether it would be possible to sample. At noon, winds were still high and we slowly began to make our way back to BIO.

JD165 – Thursday June 14, 2018 – End of Program

We arrived back at BIO at 0900. End of program.

6. EQUIPMENT AND PROCEDURES

6.1 Autonomous Underwater Vehicle Operations

6.1.1 Introduction

During Hudson 2018041, Autonomous Underwater Vehicle (AUV) surveys were undertaken to collect high resolution bathymetric, sidescan sonar and sub-bottom profiler data in water depths from 300-2800 m. During the expedition, three surveys of 7-9 hours each were conducted (Figure 17). For each survey, 2-4 hours were spent surveying at 20 m above seabed and the remaining time was spent for launch/recovery and descent/ascent. In total, AUV collected data over an area of 6.5 km^2 in total, approximately 2-2.5 km^2 per survey.

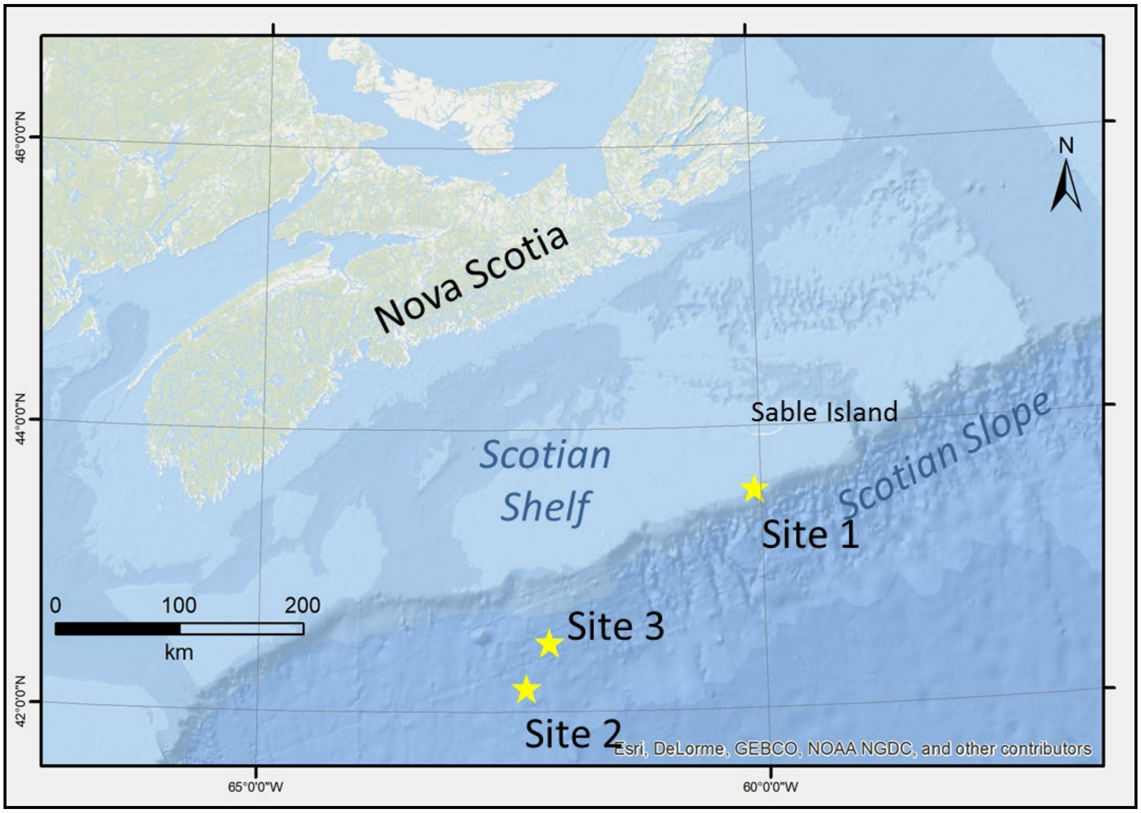

Figure 17- Map showing location of AUV surveys during 2018041.

6.1.2 AUV specifications

The AUV used during the survey was the ISE Explorer 5000 (Figure 18). The AUV Specifications are provided in Table 5. The vehicle itself and most navigation and communication system components are ~10 years old.

Table 5- AUV specifications.

Vehicle	NRCan-owned - ISE Explorer 5000 (built in Canada)
Length	7. 2 m
Weight	2200 kg (as configured)
Survey Speed	3 knots (5.5 km/h)
Max Speed	6 knots (11 km/h)
Max. Depth	5000 m
Endurance	~24 hours (as outfitted)
Survey Options	Fixed depth or bottom following (fixed altitude)

The scientific payload consisted of:

1) An Edgetech 2205 Bathymetric Sidescan sonar which provides both sidescan sonar and swath bathymetry data.
2) An Edgetech 2205 Sub Bottom Profiler
3) Ocean Conductivity, Temperature, and Depth (CTD) sensor

The sidescan sonar and sub-bottom profiler are recent upgrades installed in 2016-2017.

Figure 18- The AUV (ISE Eplorer 5000) on the flight deck on CCGS Hudson. Note the rail system for moving the AUV between the hangar and the flight deck.

The Navigation and Communication payload consists of:

1) Inertial Navigation System (INS) – Heading, Attitude, Speed, Depth, Heave.
2) GPS – Provides aiding input to INS when vehicle is surfaced.
3) Doppler Velocity Log (DVL) – Provides aiding input to INS when vehicle is tracking the seabed (range up to ~150 m). Used for bottom following navigation and obstacle avoidance.
4) Acoustic Modem – for communication during mission.
5) Iridium Satellite Beacon – for surface recovery.

Graphical representations of the AUV dive and survey patterns are shown in Figure 19, Figure 20, and Figure 21. AUV navigation is provided by an Inertial Navigation System (INS) that receives aiding from GPS and a Doppler Velocity Log (DVL). The DVL uses acoustic beams to estimate vehicle velocity relative to the seabed (bottom tracking) or the water column (water tracking). With DVL bottom tracking, positioning error is 0.1% of distance travelled. When INS is unaided for 5 minutes, positioning error is 20 m. In pure inertial mode, positioning errors are up to 1 km in 1 hour. For these surveys, the main positioning errors are from ocean currents affecting the vehicle during its descent while the DVL is in water tracking mode (Figure 19).

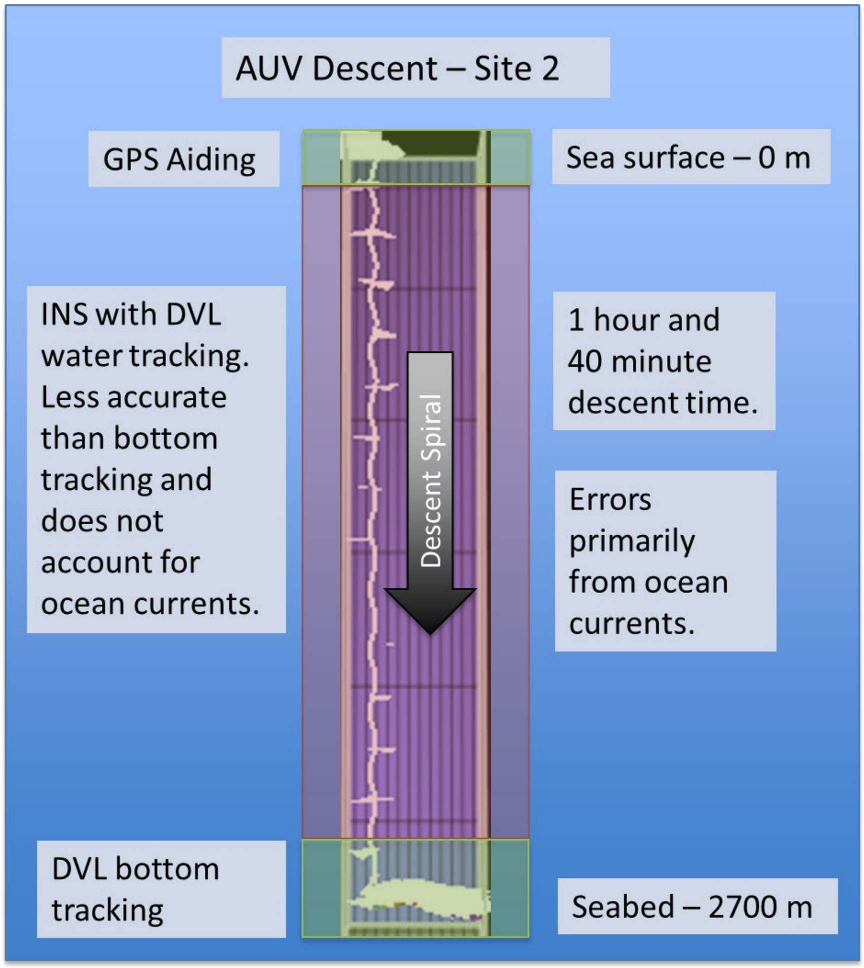

Figure 19- AUV dive and survey pattern in cross-section for Site 2.

Differencing the first GPS position after surfacing from the previous INS position gives an estimate of the positioning errors due to ocean currents. Half of the position difference (descent errors only) is then applied to the entire survey and is validated using surface data. Estimated current induced errors for these surveys were 15 m (Site 1), 150 m (Site 2), and 300 m (Site 3).

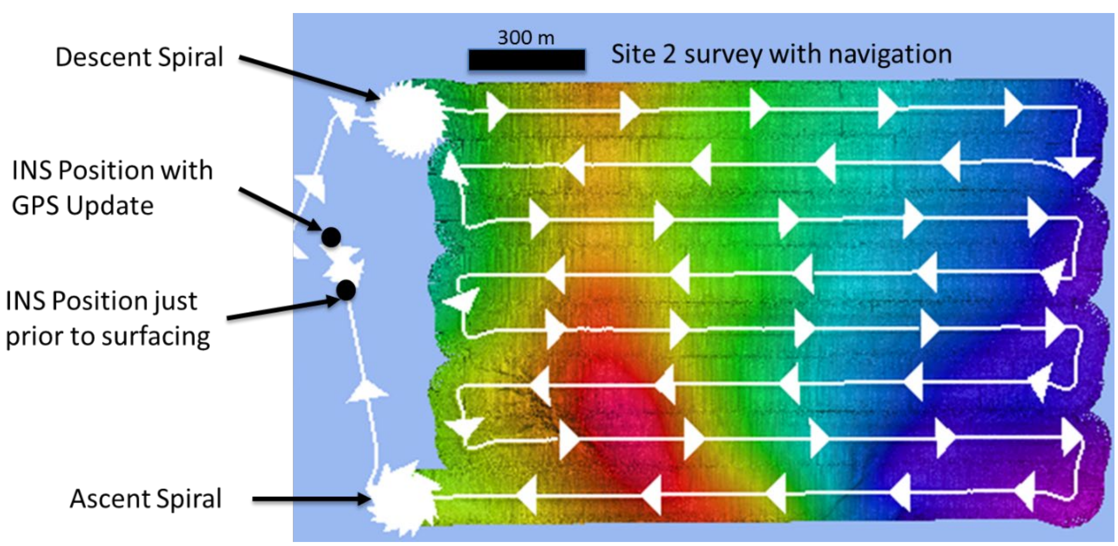

Figure 20- AUV dive and survey pattern in planview for Site 2.

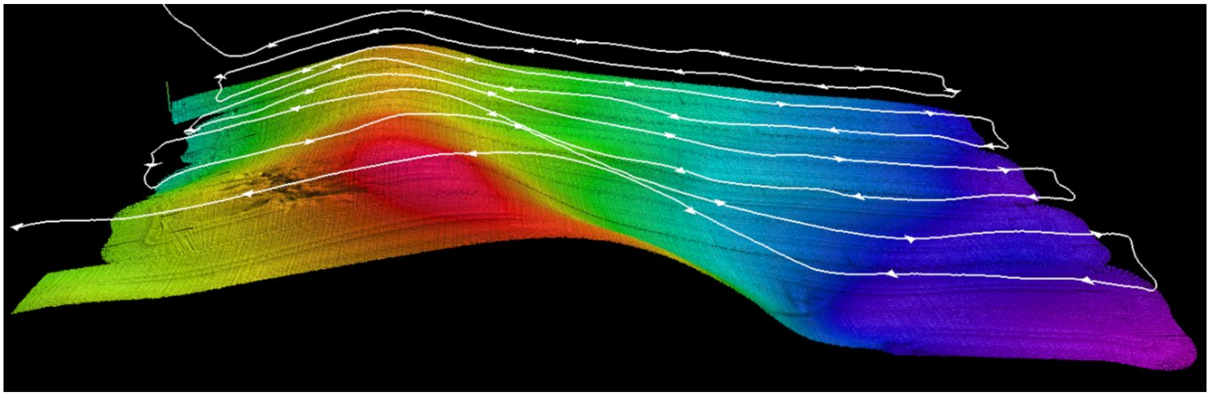

Figure 21- Site 2 perspective with AUV navigation track. Data is internally consistent due to DVL bottom tracking.

6.1.3 AUV survey pre-dive and dive procedures

Prior to each dive, a dive plan was developed in collaboration with DRDC staff and the survey was simulated on a computer in order to identify any potential errors. Without a dedicated launch and recovery system, deployment and recovery of the 2200 kg vehicle in the open ocean is not trivial and requires calm winds and seas. For Hudson 2018041, the AUV was stored in the ship's hangar between dives. Prior to deployment, the AUV was rolled out onto the flight deck on a rail system (Figure 17). Two tag lines were attached to the nose and tail of the AUV to help stabilize it during deployment and the vehicle was lowered to the sea surface using two pickup points and a quick release strap (Figure 22). Once deployed, the AUV was driven away from the ship by remote control before being set in automatic mode to begin the dive.

For a typical dive, the AUV would descend ~200 m and then "loiter" for up to an hour in order to see if any errors were present. Once a successful loiter was completed, the AUV would dive by spiraling towards the seabed. Once the survey was completed, the AUV would automatically ascend to the surface and return to its pre-planned recovery point.

Recovery of the AUV was more complicated than deployment. For recovery, the Hudson's Fast Rescue Craft (FRC) was deployed with ~7 personnel. A soft-bottom Zodiac provided by DRDC was then deployed and 3 DRDC/NRCan staff boarded the Zodiac from the FRC. The AUV was brought along-side the starboard aft quarter of Hudson by remote control (Figure 23) and the staff on the Zodiac attached the pickup straps and tag lines to the AUV. The AUV was then recovered, the staff on the Zodiac were transferred back to the FRC, the Zodiac was recovered, and the FRC with all staff was finally recovered. The FRC could not be used to attach the pickup lines to the AUV because the rigid hull of the FRC could potentially damage the fuselage of the AUV. Although the recovery involved many steps, by the 2nd and 3rd dive, it was completed in 30-40 minutes, a testament to the expertise of the Coast Guard and DRDC staff. For future surveys, the development of a more sophisticated launch and recovery system is highly recommended.

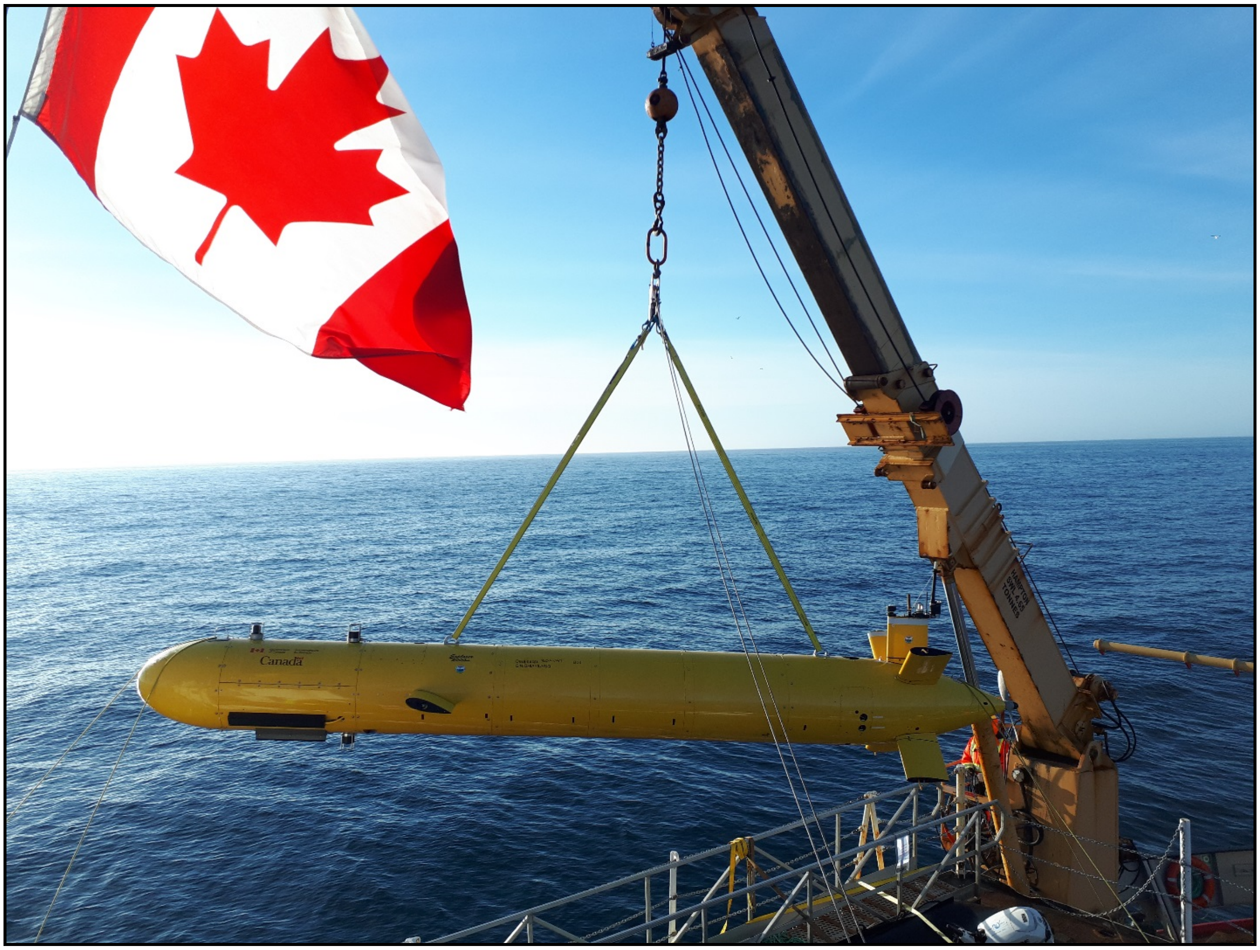

Figure 22- Deployment of the AUV from the flight deck on CCGS Hudson.

Figure 23- CCGS Hudson with AUV in foreground operated under remote control during AUV recovery.

6.1.4 AUV operations Summary

These data demonstrate the utility of NRCan's mapping AUV for collecting very high-resolution swath bathymetry, sidescan sonar, and sub-bottom profiler data in deep water environments. The increased resolution allows imaging of features that are not visible on surface collected data, which leads to an enhanced understanding of geological conditions at and below the seabed of Canada's offshore lands. The high-resolution data comes at the cost of survey area coverage and is therefore not a replacement for regional mapping. However, it is a valuable tool for targeted, site specific research. Given the utility of this data, future investment to streamline the launch and recovery process will increase the efficiency and improve the safety of survey operations. Improvements and updates to the vehicle's navigation and communication components will further improve the data quality and greatly improve the positioning accuracy.

6.2 Knudsen 3260 Echo-Sounder

During much of the cruise, a ram mounted 12 and 3.5 kHz transducer, transceiver and recorder were used to track bottom and gather sub-bottom profiles when transiting, surveying and sampling. The echosounder was used simultaneously as the Huntec DTS. No problems were encountered with this system for the duration of the cruise.

6.3 Huntec Deep Towed System

This section was modified from a report prepared by Geoforce Group Ltd. Geoforce Group Limited provided technician Tom Fralic to supervise the installation, operation and maintenance of the Huntec systems during the field program.

6.3.1 Deep Tow System

The DTS system, originally manufactured by Huntec (70) Limited, is a high resolution, sub-bottom profiler with the acoustic source, energy supply, pressure sensor, and two receiving hydrophones housed in an underwater tow fish.

The AGC #2 DTS system was used during this mission. The maximum power output of this system is 1000 joules (60 μF storage capacitance) with an ED10F/C Boomer and a twenty tip mini sparker source. The internal single element LC10 hydrophone was configured as Seismic #1. The externally towed Geoforce GF24/24P2i streamer hydrophone was connected as Seismic #2 (overall streamer length 8 m, two inter-spliced channels with a combined fourteen foot active section, total of twenty-four AQ1 elements with an effective spacing of 30cm).

The ED10FC boomer source is depth compensated and outputs a highly repeatable broadband pulse, capable of resolving 10 cm. Peak output intensity is 118 db relative to 1 micro bar at 1 meter, with a pulse duration of 110 ms. The sparker source has twenty, #18 awg, solid core tips. The peak amplitude and pulse width of the sparker source are depth dependent. Acoustic output is centered at approximately 1500 hertz, with a bandwidth of 500-2500 hertz. The sparker source was used exclusively on this mission. The deck equipment consists of a Benthos Oceanographic winch, which includes a multi-way slip ring and a 250 meter, twenty-one conductor, armoured tow cable. The winch is powered by a 440 VAC, 50 HP hydraulic pump unit. The tow cable is handled by a 36 inch diameter roller cluster rigged on the center position of the aft A frame. The lab instrumentation consists of the Geoforce Systems Console and DC high voltage power supply (PCU). The Systems Console houses the Bottom Motion Compensator circuits, the +60 DC volt fish supply, and modules for signal processing and recorder outputs. The Huntec Mk III PCU provides DC power to the Energy Storage Unit (ESU) in switchable ranges from 2 to 6 kilovolts.

6.3.2 Recording Systems for Huntec DTS

A GeoDigs 24 Bit Acquisition System (DIGS #1) was used as the digital recording device. This included a National Instruments USB 9234 Analogue to Digital Converter, and GeoDigs v1.3 software operating on a laptop running Windows 7. Trigger was provided from a MITS trigger system to enable synchronization with the GI gun system running simultaneously. Navigation Data came via the bridge through the laptop's Ethernet port and was embedded to the recorded files on GeoDigs.

Paper records were generated by an EPC 9800 Graphic Recorder using the parallel interface functionality of the Portable DIGS #1 system. Automatic and user-initiated annotation of the paper records were provided using the annotator function of the DIGS software.

Recording Parameters for Huntec DTS

<u>System Console</u>

BMC: Enabled Trigger

Source: MITS

Trigger Rate: 1000ms, 1100ms, 1200ms, 1250ms, 1500ms, 2400ms (changes in log)

TVG Rate: 4 (max)

Source Level: 4kV

Portable DIGS #2

Software: GSCA USB 9234 Mk. 1.3.1
Format: SEG Y
Storage Medium: Internal Hard Disk Drive
Sample Rate: 25.6 kHz
Record Length: 500 ms
Trigger I/P: Geoforce Systems Console Master Trigger
Analogue I/P 1: DTS Internal Raw
Analogue I/P 2: DTS External Raw
Analogue I/P 3: External TVG OP

EPC 9800

Display: DTS External Streamer
Print Density: 100 LPI
Print Gain: 36 dB (Typical)
Print Delay: 1500 ms (Typical)
Print Threshold: 0 (Typical)
Fix Marks: Timestamp @ 5 min. intervals Scale
Lines: 100 ms
Low Cut Freq.: 500 Hz Hi Cut
Freq.: 8000Hz

6.3.3 Huntec DTS Performance

DTS

The survey was performed using the recently upgraded AGC#2 system. This system had just recently received a new stainless steel 1000J Energy Storage Unit. The unit performed without flaw and collected data in water depths up to 4963 metres. At one point after a re-termination, the Leak Alarm was intermittently sounding off on the System's Console, this was a result of two twisted pair wires shorting out within the termination block, and was repaired when discovered.

Portable DIGS #2

This recorder operated the entire program without issue.

EPC 9800

This recorder operated the entire program without issue.

Consumables

Two o'rings and a Cinch Jones female connecter were used during this phase.

6.4 Gravity Coring

The gravity coring system used was the AGC Long Corer which uses coupled core barrel sections in 10 ft (305 cm) lengths. This coring system was used as the primary long coring system on this cruise because of the presence of the AUV. The AUV limited available space on the deck, so it was not possible to operate the standard piston corer. The device was rigged using two to three barrels, allowing a maximum penetration of 915 cm. The core head itself is 3 m long, 0.6 m in diameter and weighs approximately 1350 Kg. Each barrel has an internal diameter of 4.25" (10.8cm), a 3/8" (9.5mm) wall thickness with twin exterior Victaulic type grooves cut at each end. Pipe sections are joined using exterior couplings which are secured by set screws into grooves. The barrels are lined with Cellulose acetate butyrate (CAB) plastic pipe which is also in 10 ft (305cm) lengths to return sediment core samples with an outer diameter of 99.2 mm. A split piston with O-rings and a variable orifice size (split piston orifice used for the first two cores was 7/64" then we switched to 3/32") and a standard core catcher was used at all coring sites.

The ship's large Pengo winch was used for coring with ¾" wire cable. The North Pacific foredeck crane was used to deploy and recover the heavy coring equipment. The corer was handled on deck using a system that included a rotating core-head cradle, outboard support brackets, a monorail transport system with 2 one-ton chain hoists, a lifting winch and a processing half-height container. Each recovered core was broken down at the barrel joints and moved to the processing half-height container via the monorail, where each 10ft (305cm) section of liner was extruded from the barrel and cut in half and labelled.

The corer worked reasonably well and provided a good compromise between penetration and turn-around time between core samples. However, penetration was typically much less than the standard piston corer.

6.5 Onboard piston core processing and subsampling

All cores were processed according to standard GSC Atlantic core procedures. Cores were identified alphabetically by section at the time of dismantling from the bottom to the top, commencing with the bottommost core barrel and proceeding to the uppermost barrel containing sediment. Each 305 cm length of liner was extruded from the barrel and cut in half, using a modified pipe cutter, in the half height container. The sediment in the liner was cut using a wire saw and the section ends were carefully capped to minimize disturbance to the sediment surface. The top end cap was labelled with the cruise number, station number, section label and top. The base of the core is designated with the letter A and the top of the base section is designated as B. The base section is AB. Each section was brought into the GP Lab and stored horizontally on the benches. Each core, starting with the base section AB, was processed using the following procedure. The core liner was labelled with an up arrow, cruise number, station number, section label and the top and base of the section were labelled with the appropriate letter.

The top and base of every section was considered for physical property measurements and given the appropriate conditions, strength measurements and constant volume samples were taken. Core sections were split longitudinally from surface and down the core as soon as possible after being collected. The plastic liner was cut longitudinally using the GSC-A Duits splitter and the sediment itself was split longitudinally by pulling a piece of fine wire through the sediment along the cuts in the plastic core liner. The two core halves were designated archive and working. Each half was labelled with an up arrow, cruise number, sample number and section information. Metre tape was placed along the length of the split core section to indicate down-core depth.
The two halves were separated to undergo different analyses. The archive half was photographed, measured for colour reflectance, and described visually. The working half was viewed by Jamie Webb and University of Calgary researchers for selection of subsample locations. The core halves were covered with plastic wrap, sealed in labeled plastic core sleeving, placed in labelled plastic D-tubes and stored at 4°C in a refrigerated container until their return to BIO.

6.5.1 Physical properties measurements

Undrained shear strength measurements and constant volume samples were taken at the ends of each section if the condition of the sediment allowed. The constant volume sampler was inserted into the end of the section, the undrained shear strength measurement was taken and then the constant volume sampler was removed. The undrained shear strength was measured using a hand-held Hoskin Scientific Torvane according to ASTM Test Method D2573-94 Standard Test Method for Field Vane Shear Test in Cohesive Soil. The dial on the Torvane was zeroed, the fins on the vane were gently pushed into the sediment until they were completely inserted. The dial was rotated at a constant rate until the sediment failed.

The Torvane dial reading ranges from 0 to 1 and reports values in kg-force/cm2 units (1 kg/cm^2 = 98.07 kPa). The Torvane has three adapter vanes as described below:
L - Sensitive vane has a range of 0 to 0.2 Kg-force/cm^2
Su = dial reading * 0.2 Kg-force/cm^2
M - Regular vane has a range of 0 to 1.0 Kg-force/cm^2
Su = dial reading * 1 Kg-force/cm^2
S - High capacity vane has a range of 0 to 2.5 Kg-force/cm^2
Su = dial reading * 2.5 Kg-force/cm^2

During the cruise, the sensitive and regular vanes were used for a total of 24 undrained shear strength measurements.

Constant volume samples for bulk density and water content determinations were taken by inserting stainless steel samplers of a known volume. Prior to insertion, the sampler was lightly sprayed with Pam cooking oil and gently wiped with a small Kimwipe tissue. The bevelled edge of the sampler was placed on the flat sediment surface and the carefully inserted into the sediment at a constant rate using two flat headed spatulas. The sampler is inserted at a constant rate to minimize compression of the sediment within the sampler. The sampler was then carefully removed and the sediment was trimmed using a wire saw and extruded into a pre-weighed 1 oz screw-top glass bottle.

The bottle cap was then labelled and sealed using electrical tape to prevent the lid from loosening. A total of 33 constant volume samples were taken during the cruise. The samples will be weighed, dried at 105°C for 24 hours and re-weighed to determine bulk density, dry density and water content according to ASTM Test Method D 2216-90 (revision of 2216-63, 2216-80) Standard method for laboratory determination of water (moisture) content of soil and rock.
All relevant information for the strength measurements and constant volume samples was recorded on data sheets and input into Excel spreadsheets and will be incorporated into the physical property database.

6.5.2 Core Photography

The archive half of the core was photographed using a Nikon D300 12.3 megapixel digital camera. Overlapping digital photographs were taken at two scales. The first was a close-up image covering a 30 cm interval, and the second was a long shot image covering a 90 cm interval. The images were saved in raw, tiff and jpeg formats.

6.5.3 Reflectance Spectrophotometry

High accuracy measurements of spectral reflectance on the split core surface were made over wavelengths of 400 to 700 nm using the Konica Minolta Spectrophotometer CM-2600d. Tristimulus values X, Y and Z were derived from the colour reflectance spectra according to the Commission

Internationale d'Eclairage (CIE) method. The L*a*b* system (CIELAB) represents coordinates in 3 dimensional space where the L* is the vertical axis representing lightness and a* b* are horizontal radii representing chromaticity. The L* value ranges from zero (black) to 100 (white). The a* value represents green (-) to red (+) and the b* value represents blue (-) to yellow (+).

A zero calibration was performed to compensate for the effects of any change in the optical system and changes in ambient and internal temperature. White calibration was done using a white ceramic calibration cap and sets the maximum reflectance to 100%. Zero calibrations were performed daily and white calibrations were performed at least once daily. Prior to spectral reflectance measurements, the core was carefully covered with Glad® Cling Wrap taking care to minimize the presence of air bubbles between the sediment and the plastic wrap. Measurements on the CM-2600d were taken every 5cm and interfaced with a computer using the SpectraMagicTM NX software.

6.5.4 Sample Description

The written laboratory descriptions for the sediment cores includes: 1) condition of sample (e.g. cracks, disturbance, oxidation), 2) consistency of sample (e.g. soft, hard, firm, 3) reaction to hydrochloric acid which indicates the presence of calcium carbonate, 4) colour based on the Munsell soil colour charts and 5) visual core description consisting of colour, texture, grain size, bedding, contacts, bedforms, structures, presence of organic material, bioturbation and any other visible feature.

6.5.5 Geochemical subsampling

All cores collected were subsampled for geochemical analysis. Upon core retrieval, a headspace gas sample was immediately taken 5 cm from the base of the core. This whole round sample was divided in two, with each half placed in a separate IsoJar, and then flushed with nitrogen. If gas cracking and bubbling or a positive gas detector measurement were present, then additional gas samples were taken. After the core was split, the working half was viewed under UV light to determine possible presence of hydrocarbon fluorescence. Three sediment samples were then taken per core from a minimum of 1 m from the top of the core, to sample only anoxic sediment. These samples targeted fluorescing sediment, sandier intervals or darkened organic rich bands in the core. The samples were again divided in two and wrapped in aluminum foil. All samples were placed in a -20°C freezer to limit bacterial growth, and remained frozen until they undergo analysis at a lab.

6.5.6 Additional geomicrobiology and geochemical sampling

Most cores were subsampled by the University of Calgary and Saint Mary’s University researchers for additional analyses.

APPENDIX A- TRACK MAP AND ANCILLARY INFORMATION AT EACH STATION

Results at each station are given in Appendix A, Figures A-1 to A-15.

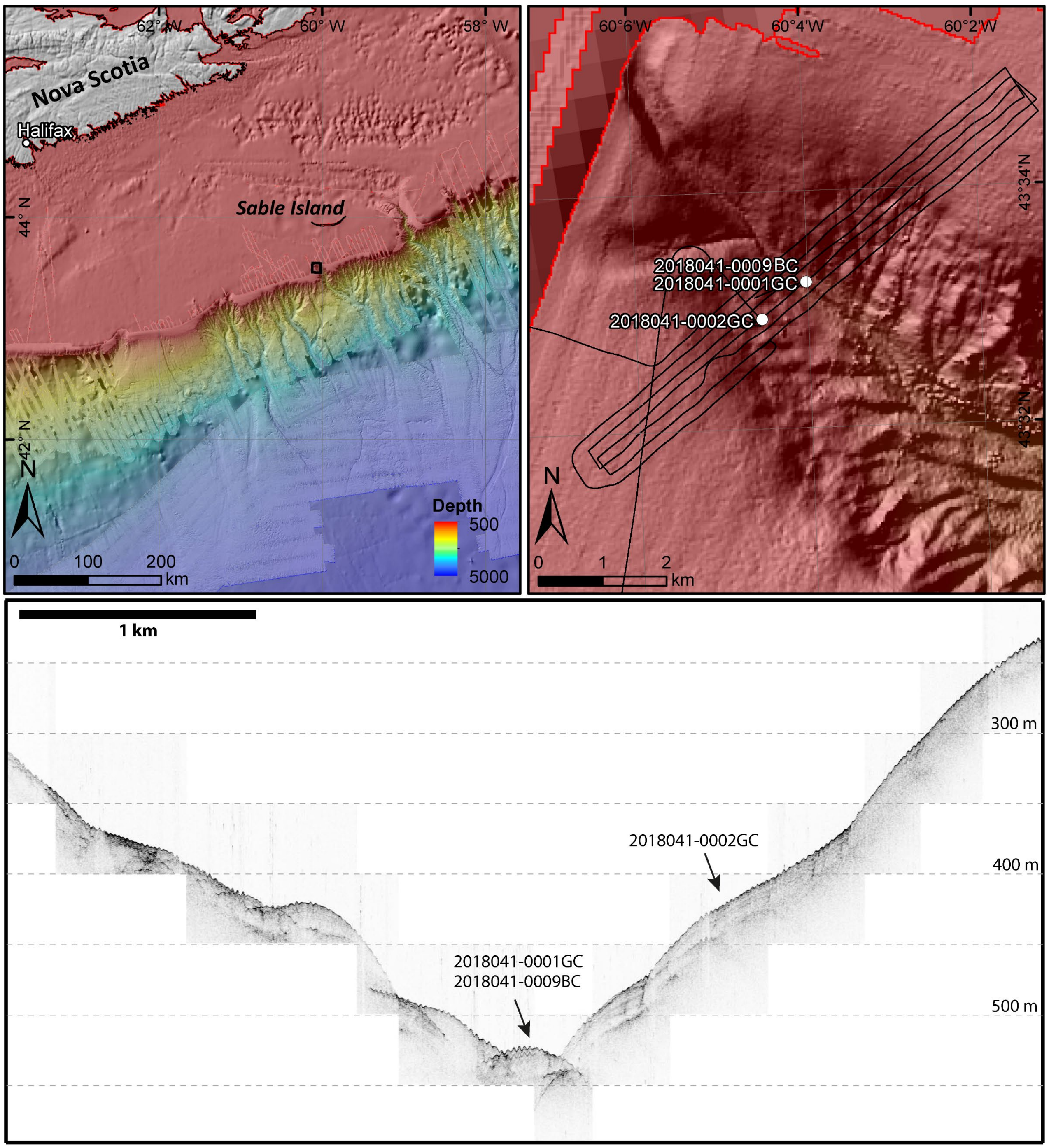

Figure A- 1: Location of cores 0001GC, 0002GC and 0009BC.

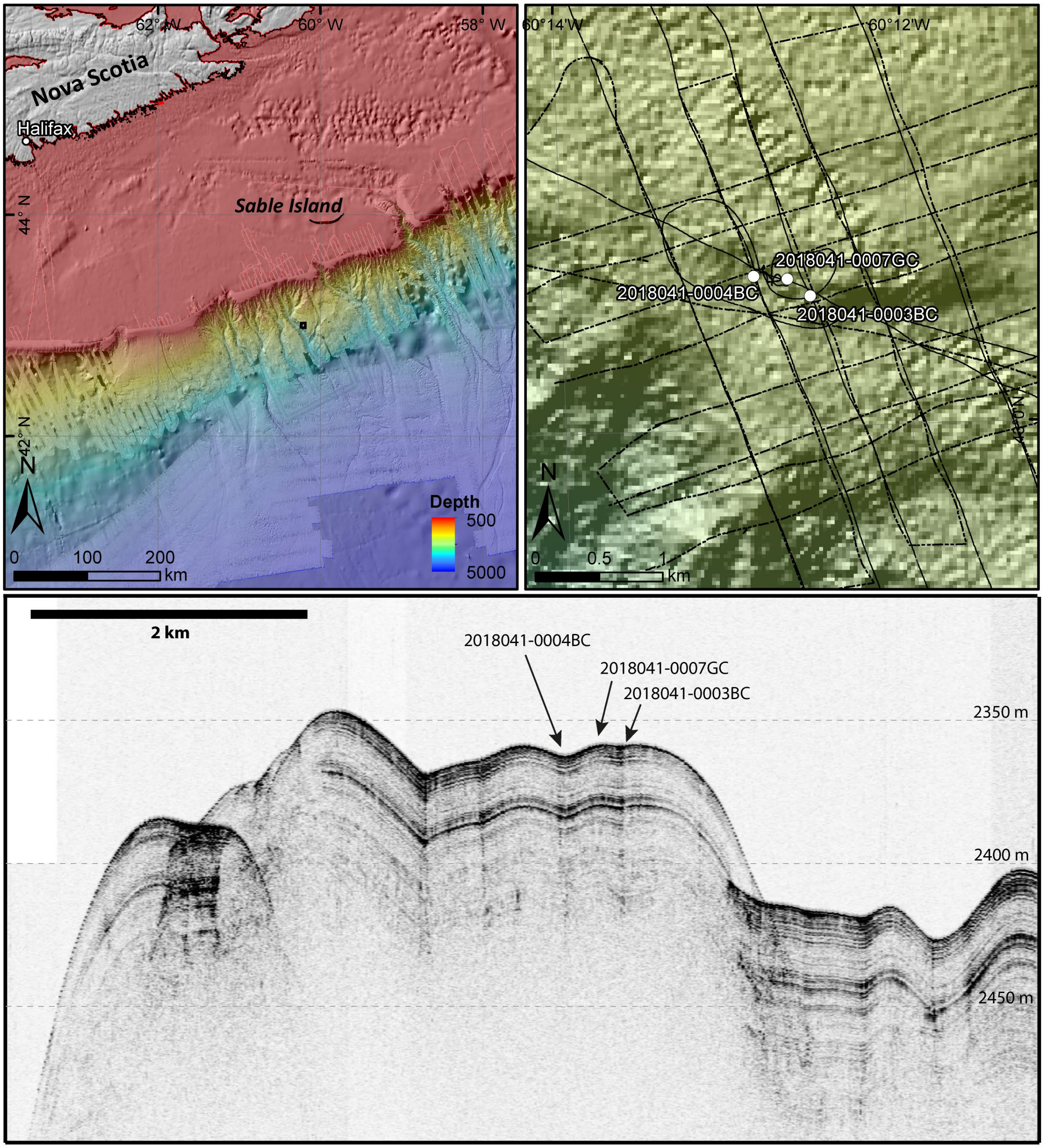

Figure A- 2: Location of cores 0003BC, 0004 BC and 0007GC.

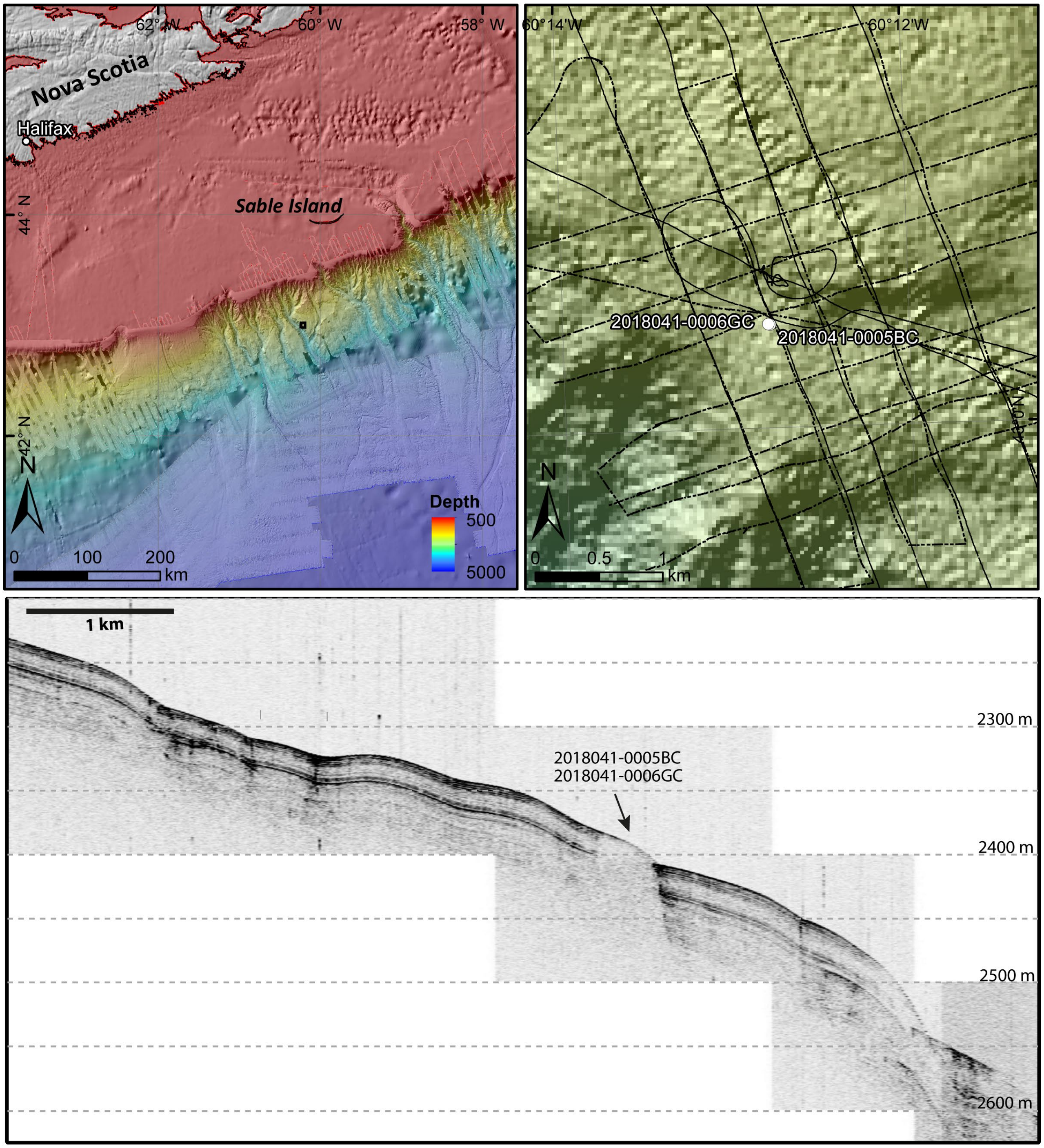

Figure A- 3: Location of cores 0005BC and 0006GC.

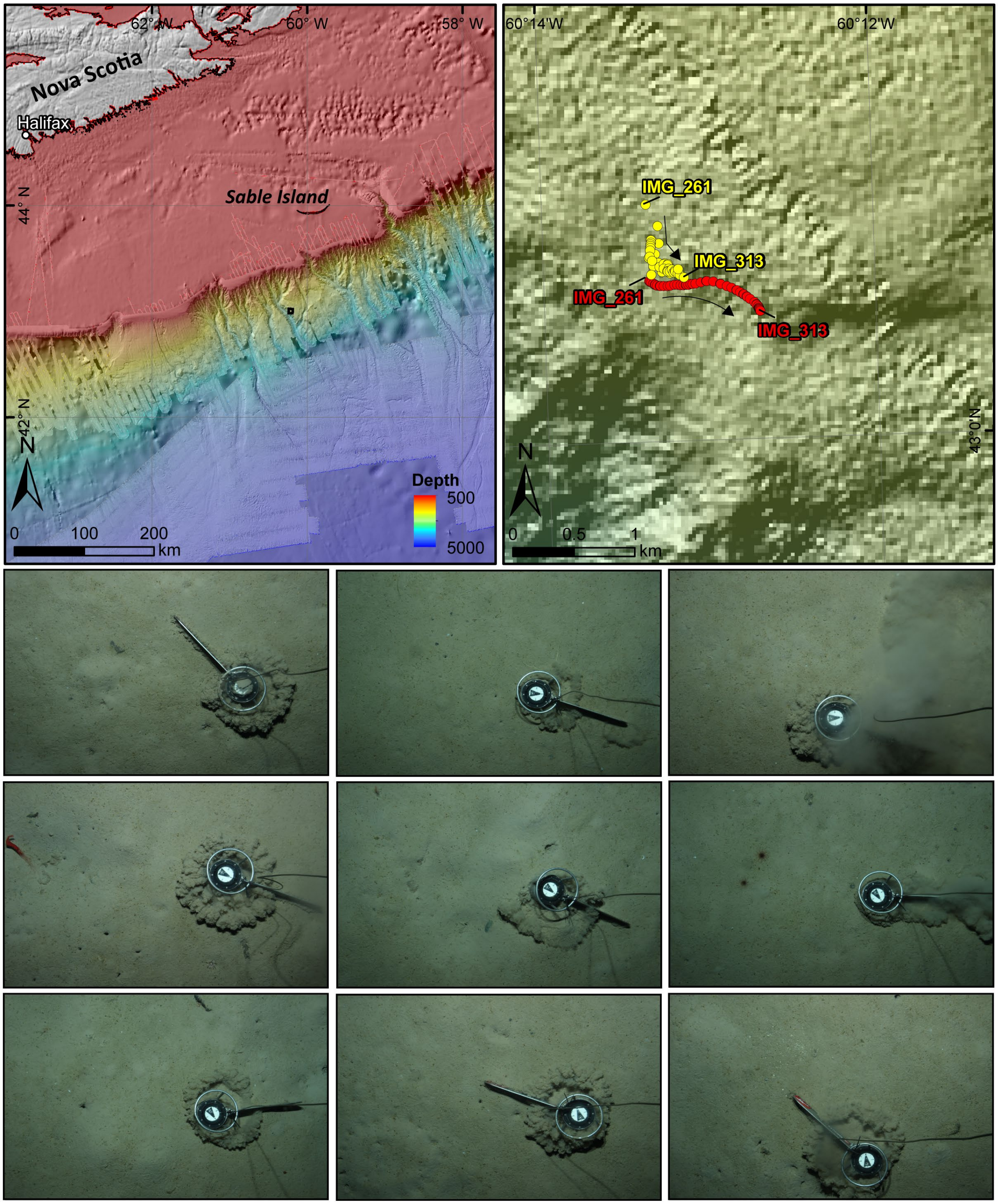

Figure A- 4: Location of camera station 0008 with examples of bottom photographs. Red dots represent ship position and yellow dots represent location of bottom photographs according to the Trackpoint.

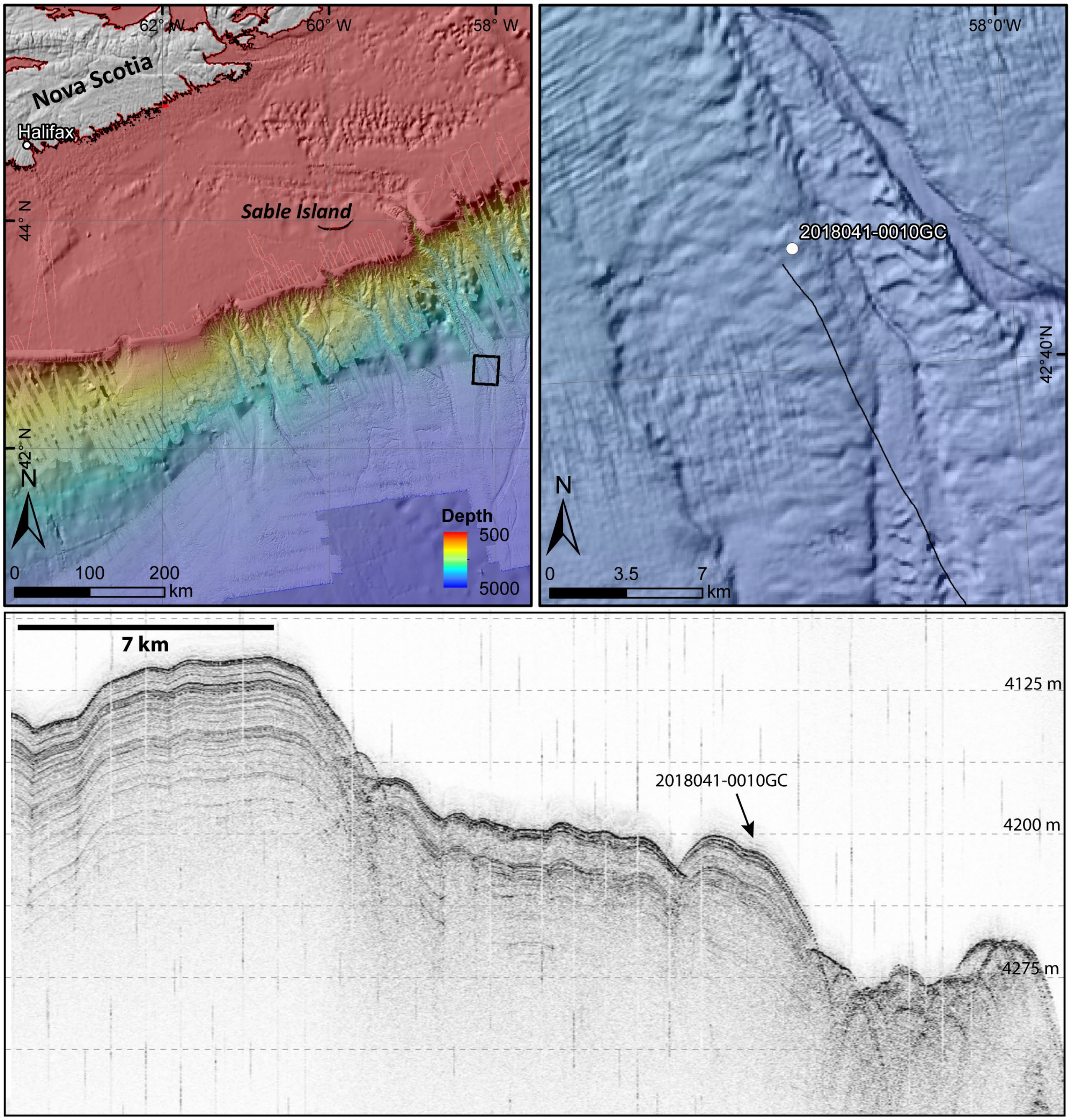

Figure A- 5: Location of core 0010GC.

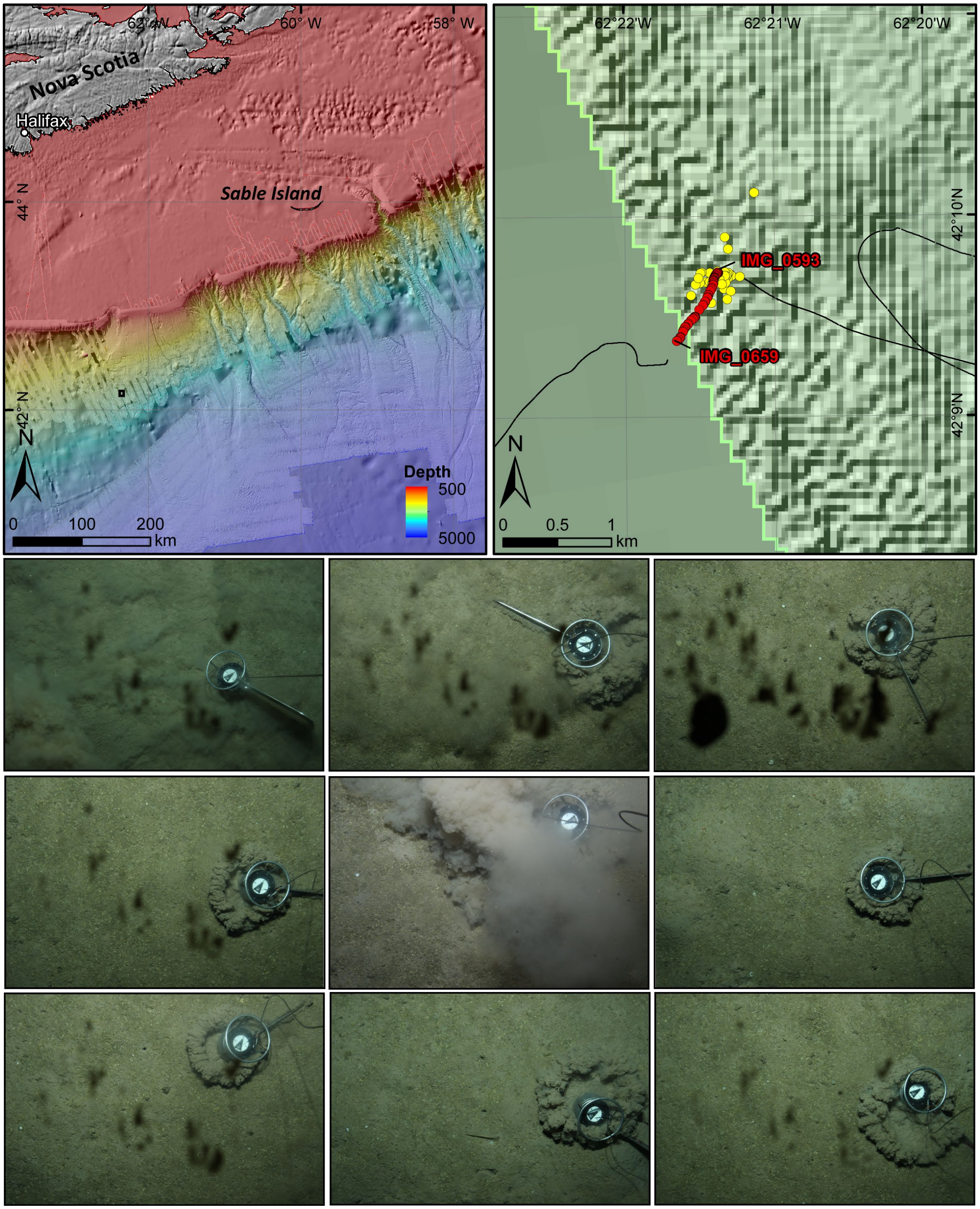

Figure A- 6: Location of camera station 0011 with examples of bottom photographs. Red dots represent ship position and yellow dots represent location of bottom photographs according to the Trackpoint.

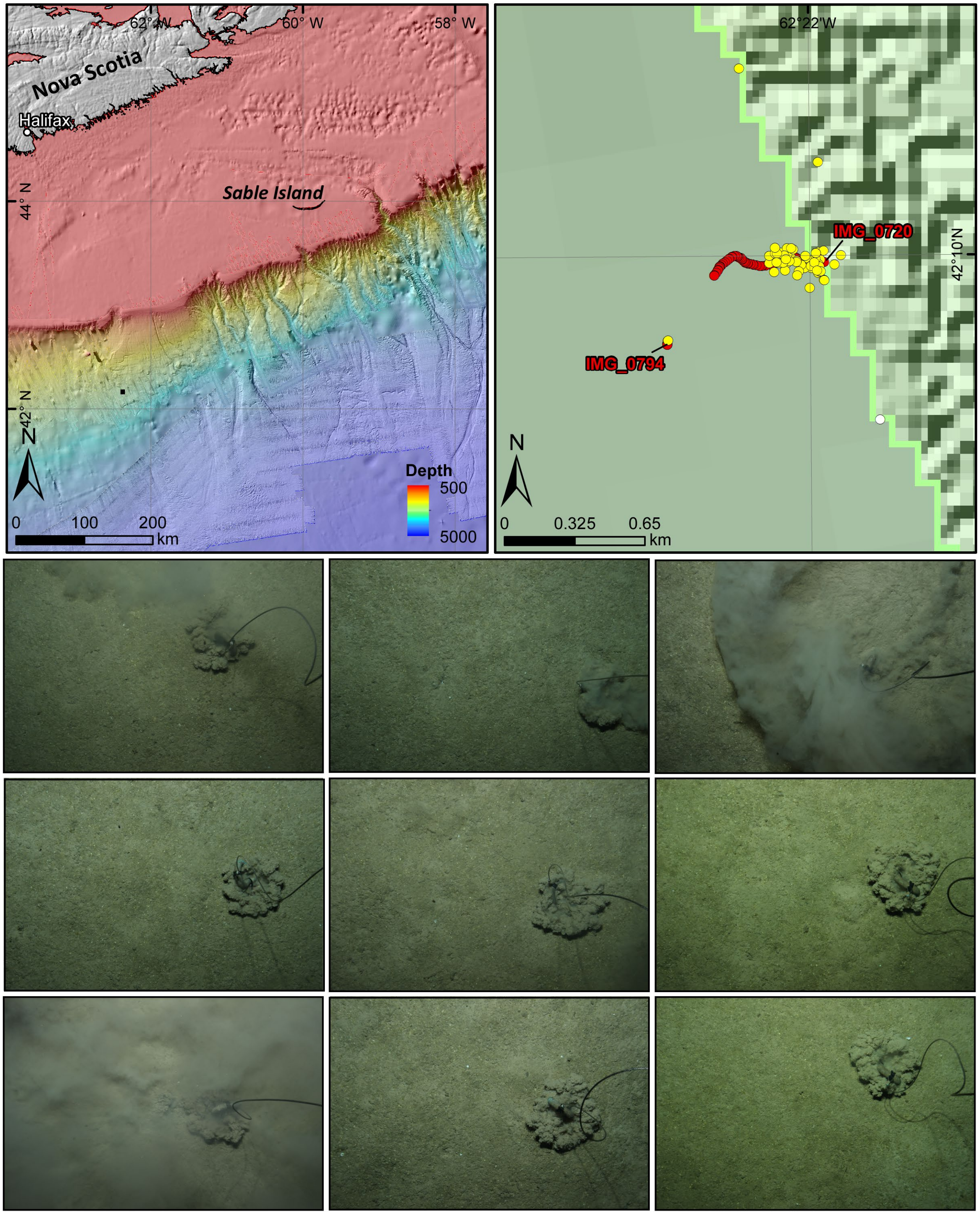

Figure A- 7: Location of camera station 0012 with examples of bottom photographs. Red dots represent ship position and yellow dots represent location of bottom photographs according to the Trackpoint.

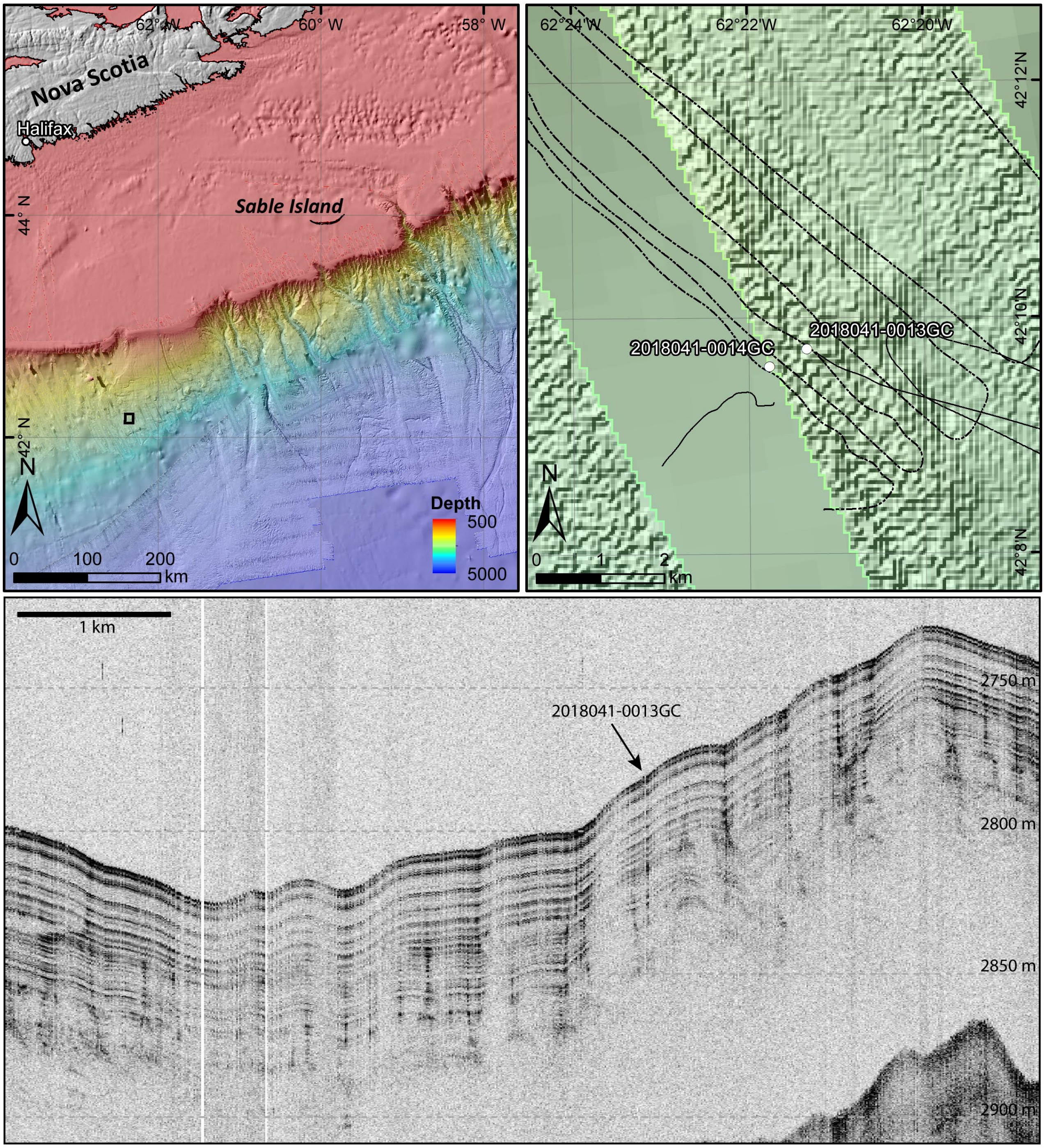

Figure A- 8: Location of core 0013GC.

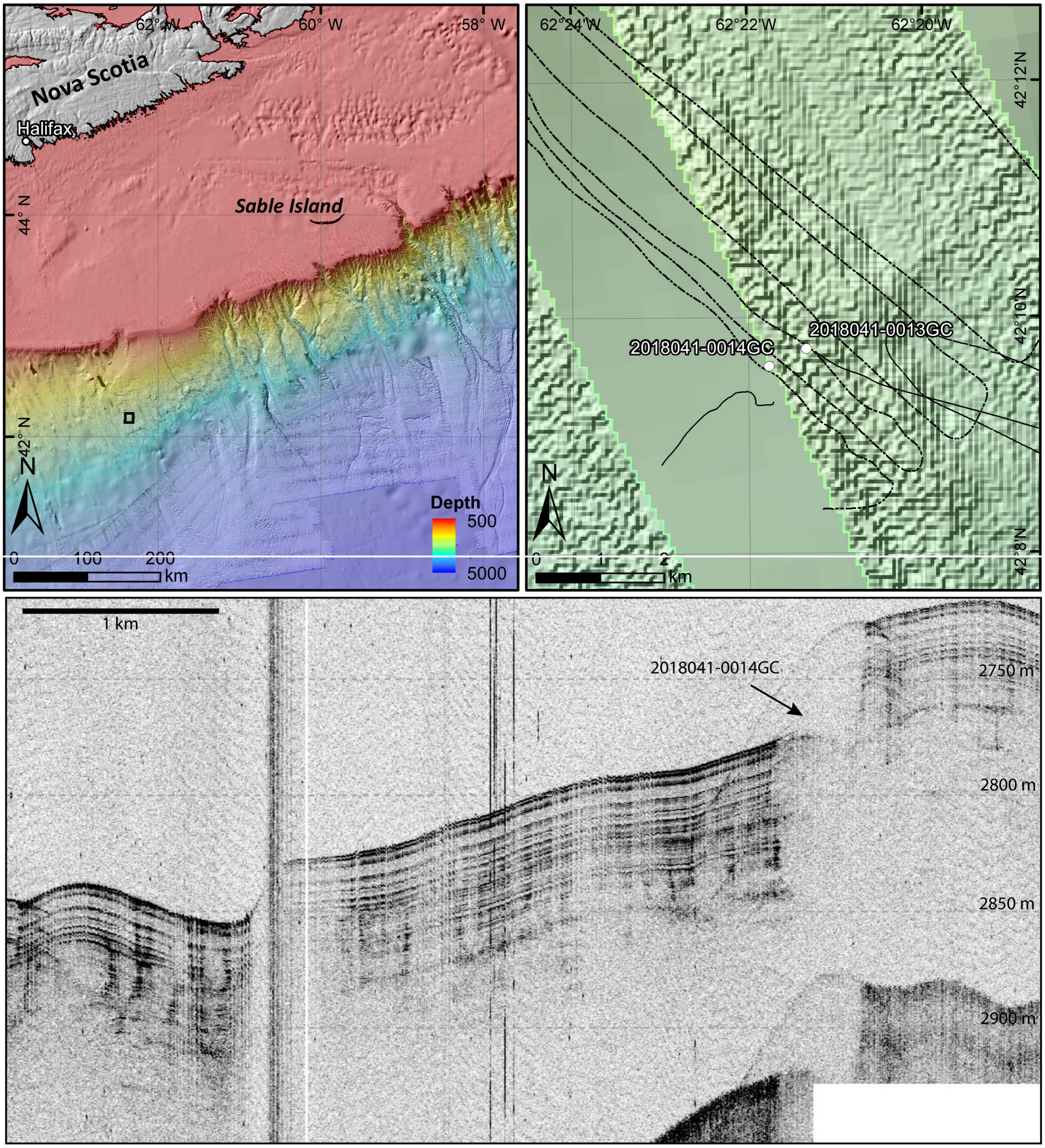

Figure A- 9: Location of core 0014GC.

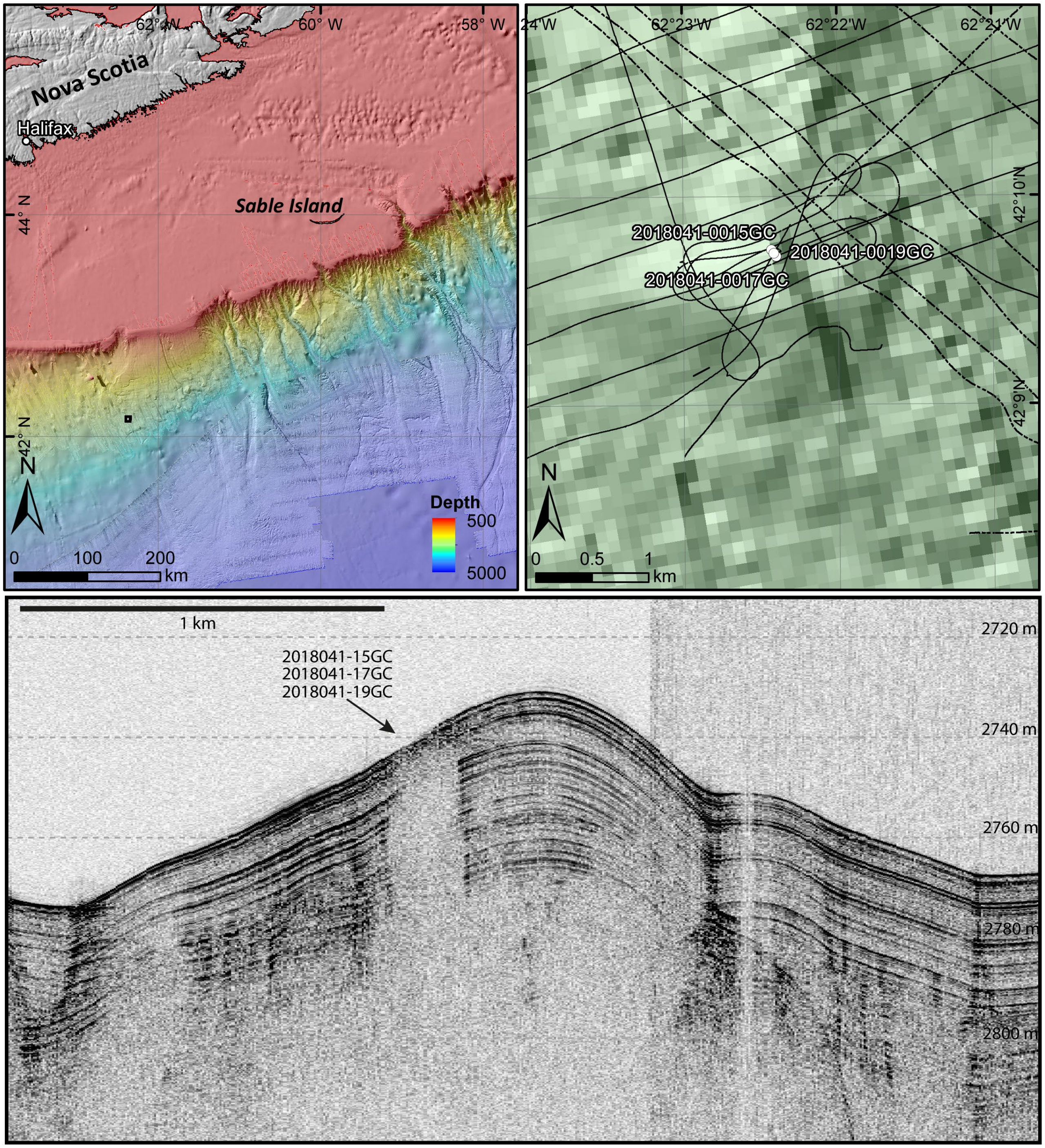

Figure A- 10: Location of core 0015GC, 0017 GC and 0019GC.

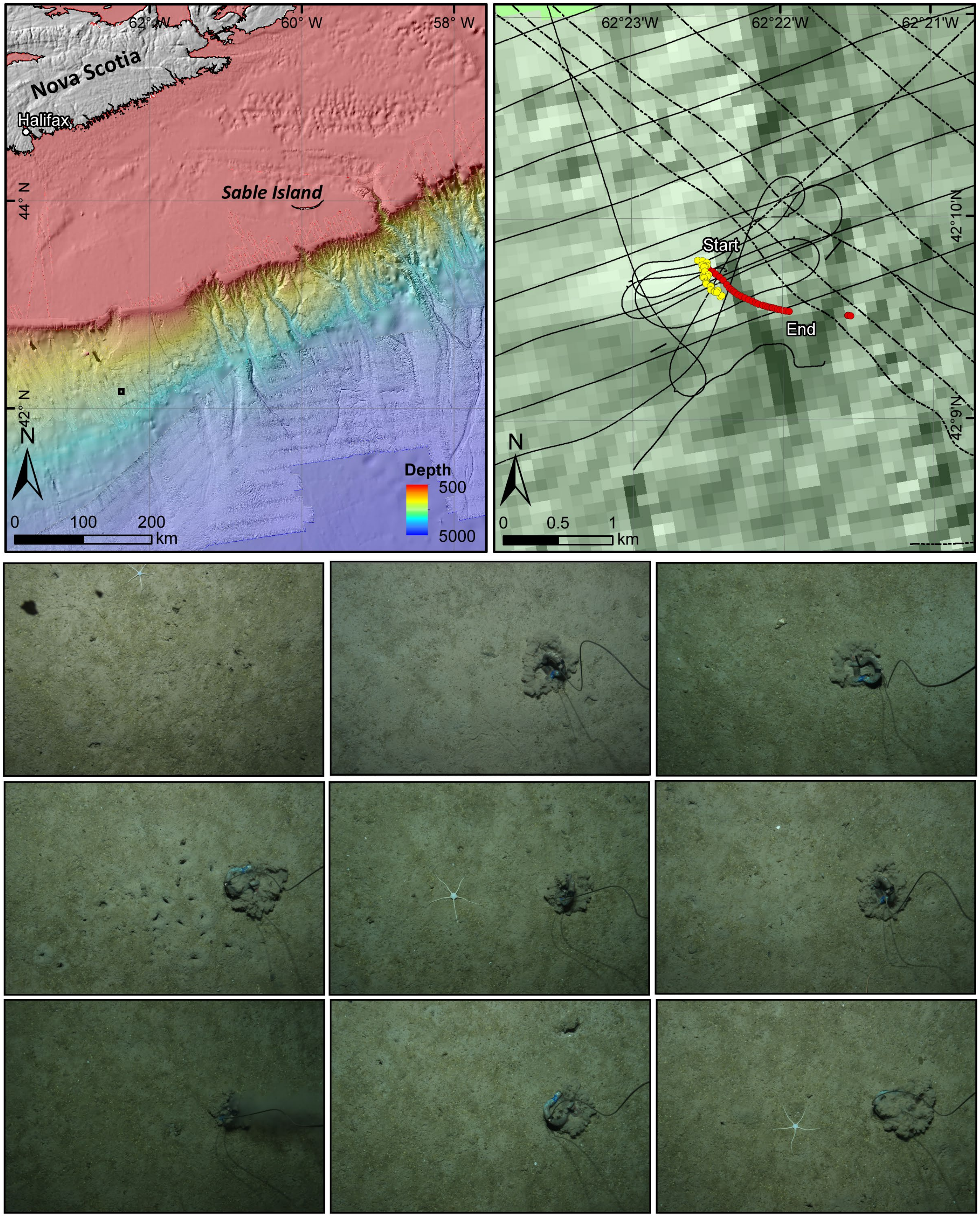

Figure A- 11: Location of camera station 0016 with examples of bottom photographs. Red dots represent ship position and yellow dots represent location of bottom photographs according to the Trackpoint.

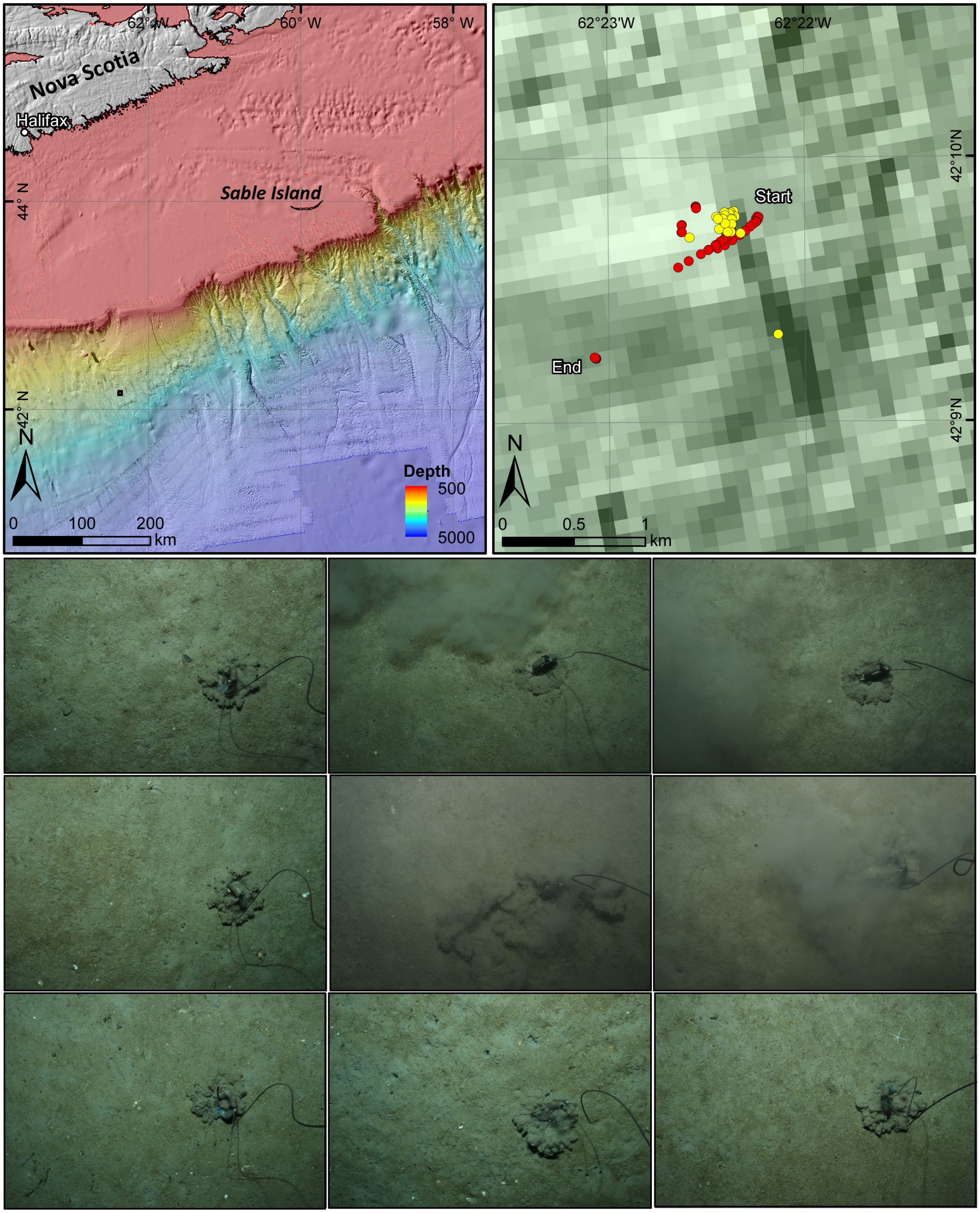

Figure A- 12: Location of camera station 0018 with examples of bottom photographs. Red dots represent ship position and yellow dots represent location of bottom photographs according to the Trackpoint.

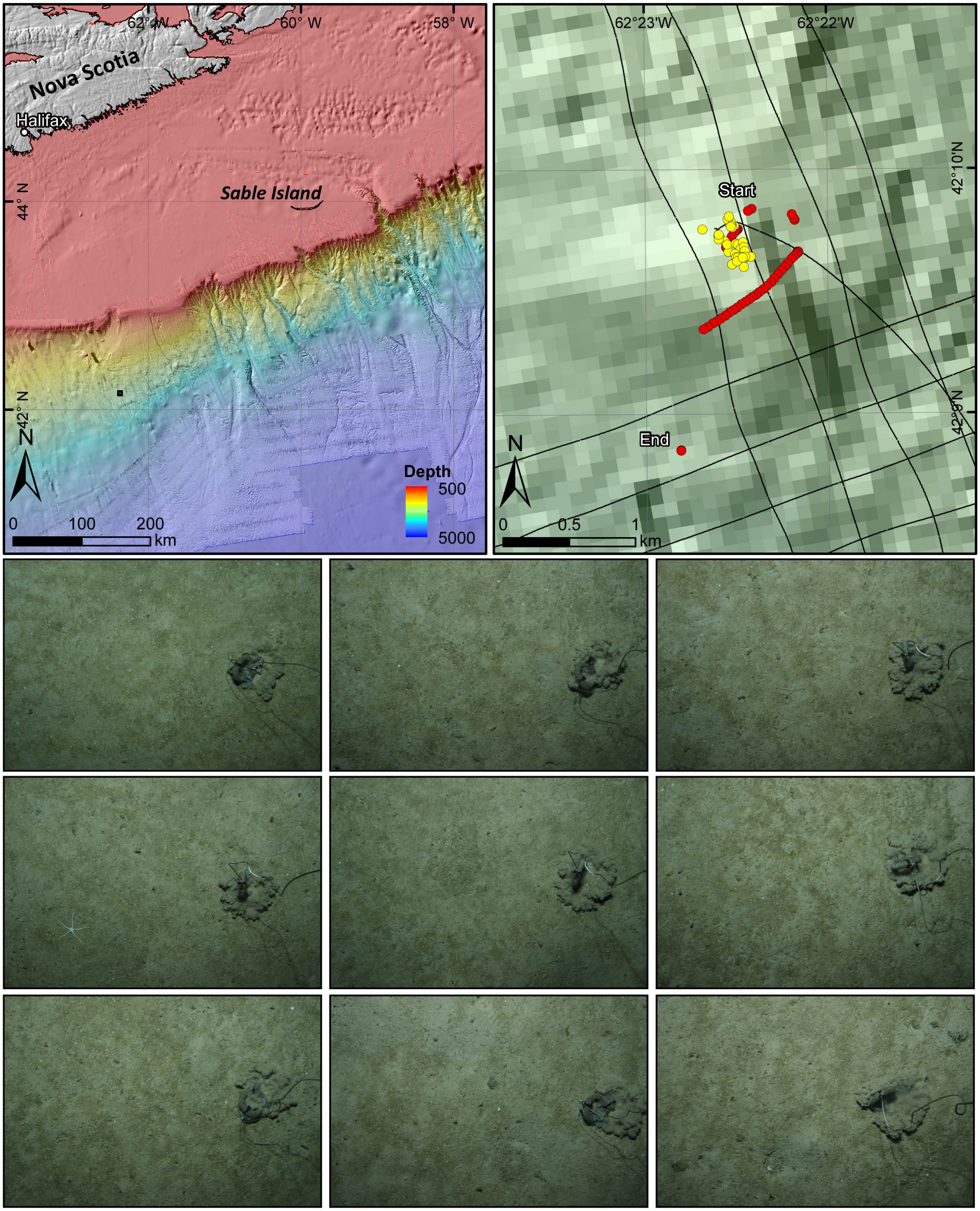

Figure A- 13: Location of camera station 0020 with examples of bottom photographs. Red dots represent ship position and yellow dots represent location of bottom photographs according to the Trackpoint.

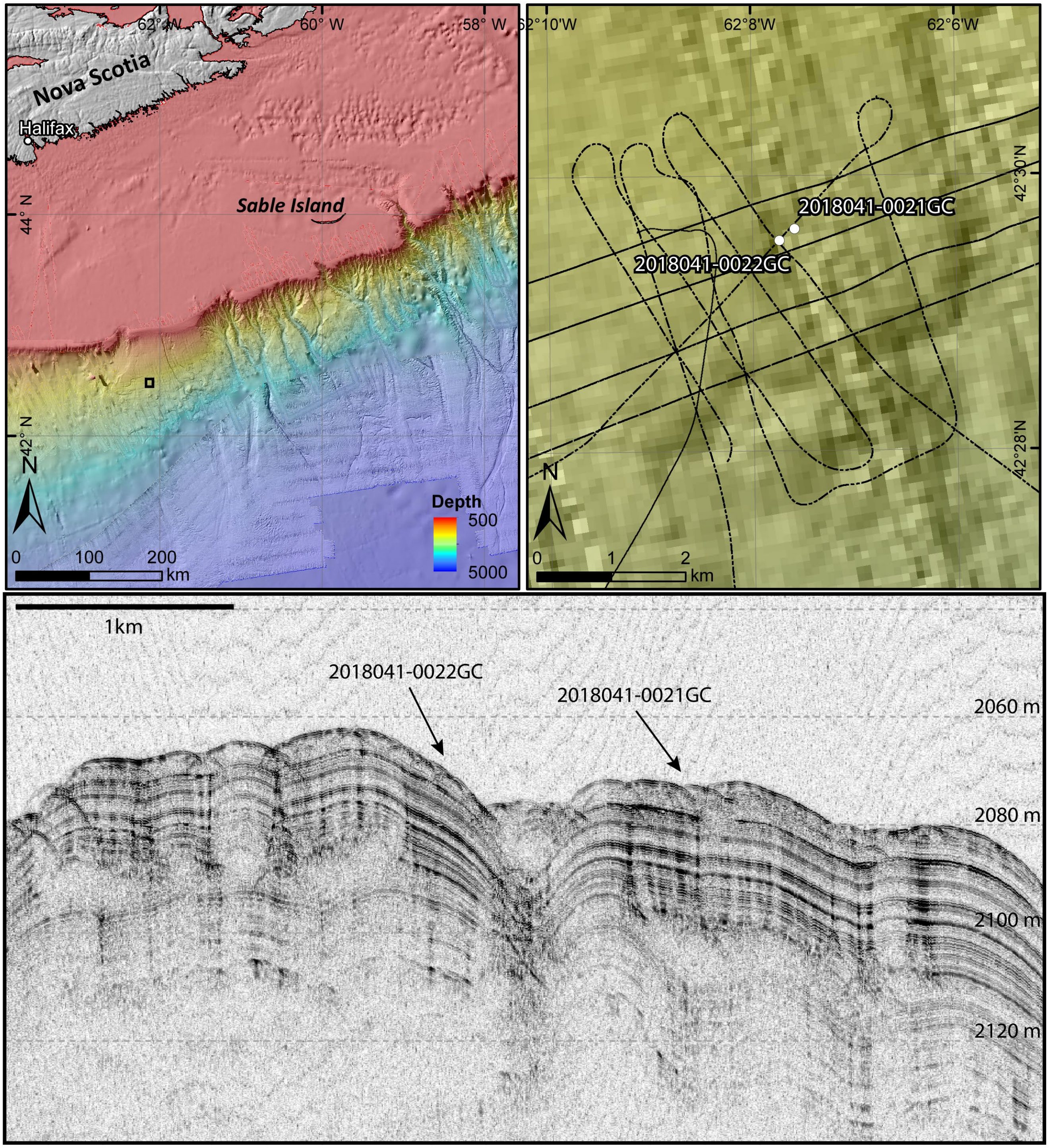

Figure A- 14: Location of cores 0021GC and 0022GC.

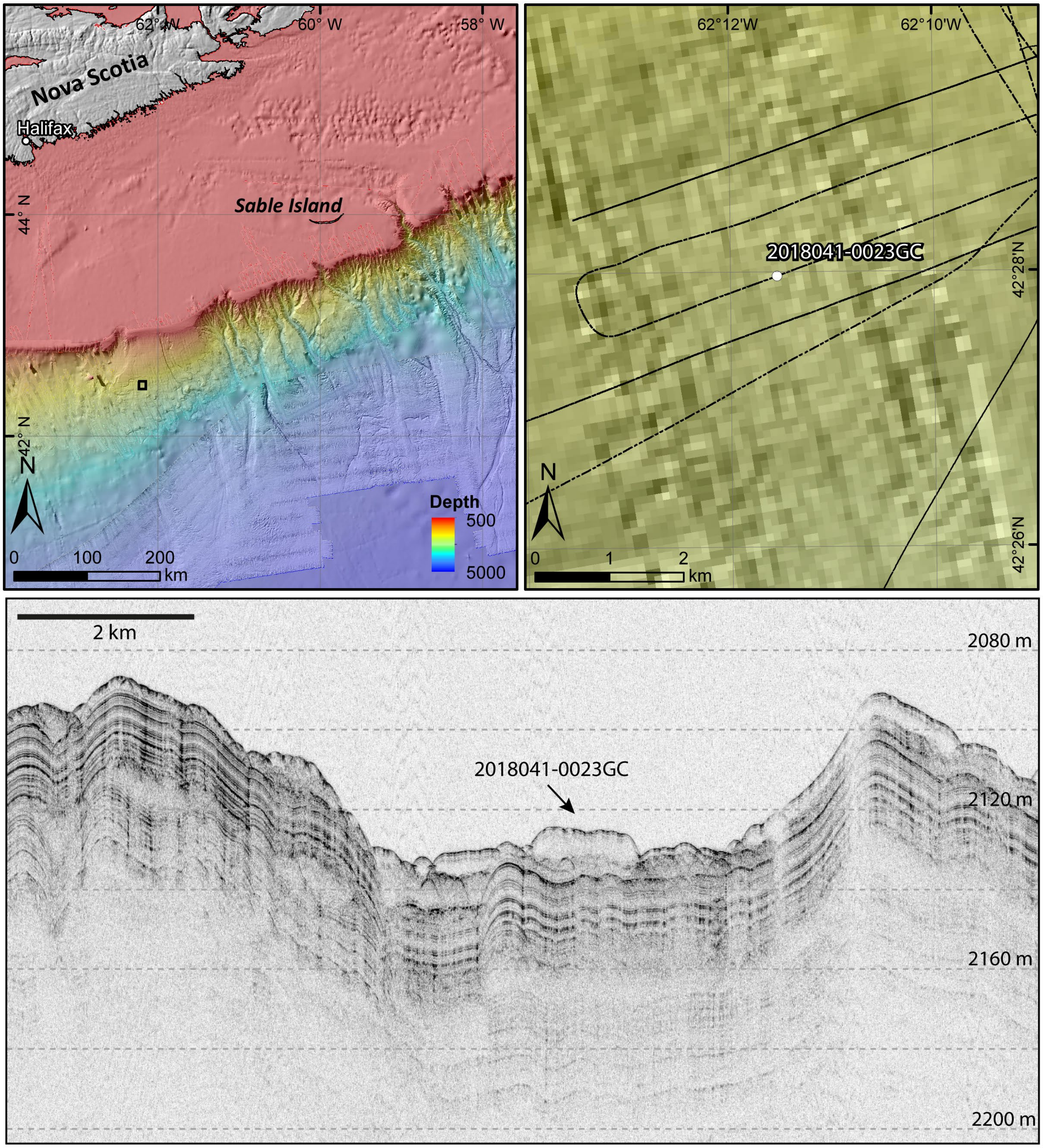

Figure A- 15: Location of core 0023GC.

APPENDIX B- PRELIMINARY RESULTS OF AUV SURVEYS.

Figures B-1 to B-10 depict preliminary results from the AUV surveys during 2018041.

AUV Site 1 – Head of Logan Canyon

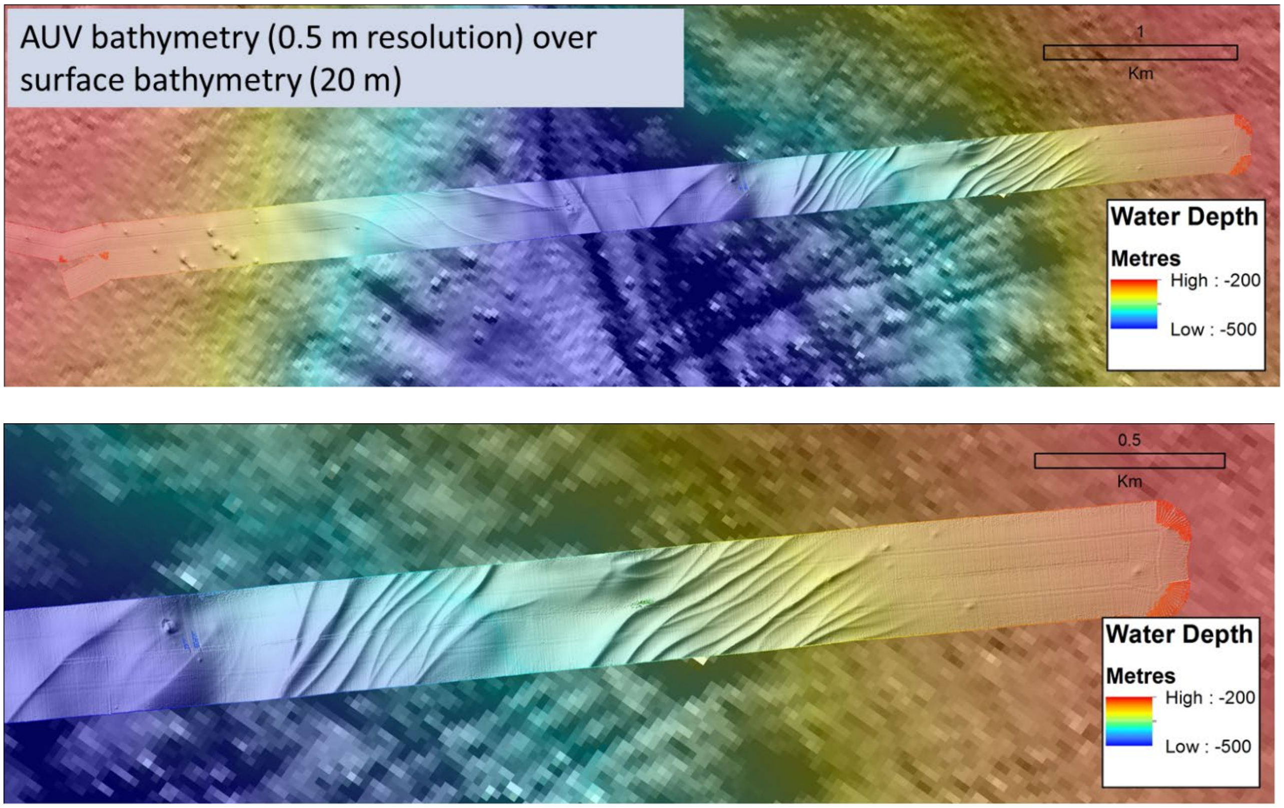

Figure B- 1: Gullies visible on surface data but their true morphology is only apparent on high resolution AUV data.

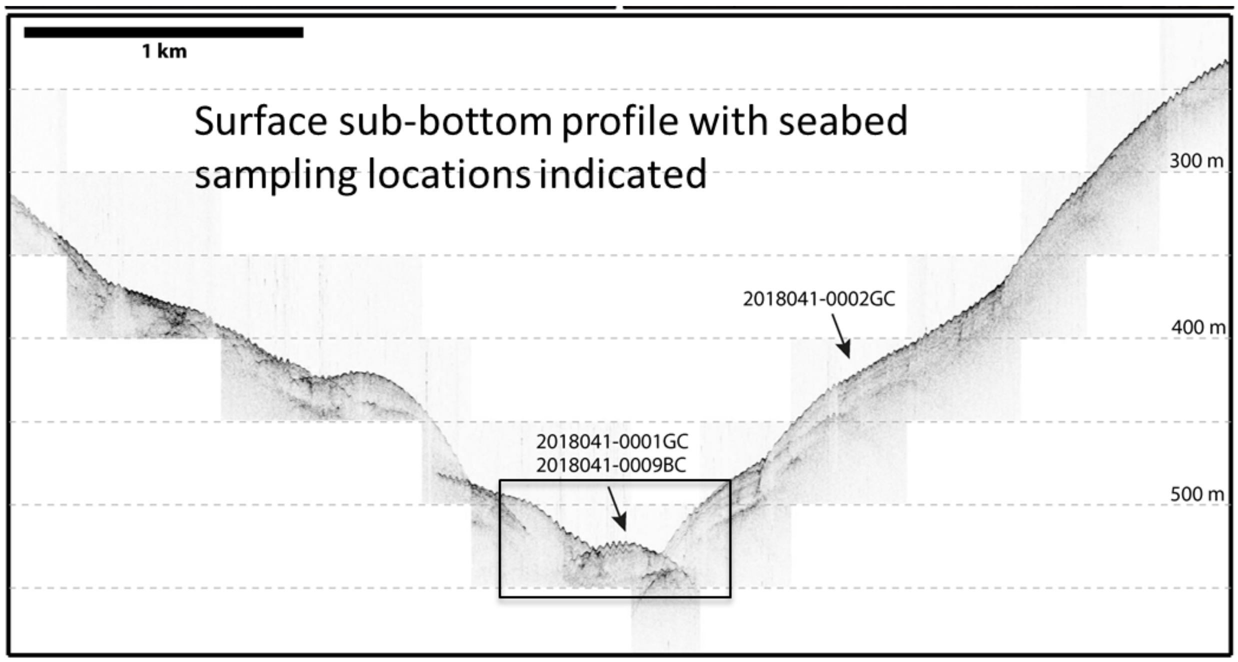

Figure B- 2: Surface-acquired sub-bottom profiler data at AUV site 1. Square box is illustrated in Figure B-3.

Increased resolution leads to new questions and challenges. Precise sampling of small targets is difficult in deep water.

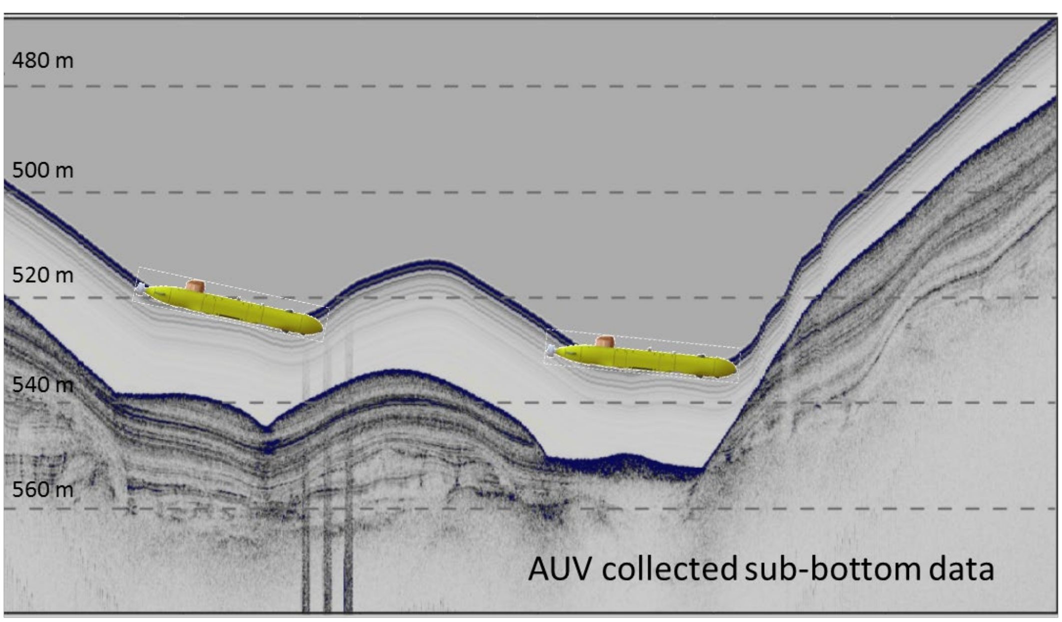

Figure B- 3: AUV sub-bottom profiler data at site 1. Note that channel thalweg is not clearly imaged on surface data.

Beam pattern or 'footprint' is a function of water depth or source to seabed distance. By operating close to the seabed (20 m), NRCan's AUV provides improvements in spatial resolution of 50 to 100 times that of the surface collected data.

AUV Site 2 – Potential Cold Seep on Crest of Salt Diapir in 2700 m water depth

Cold seeps occur where fluids, such as hydrocarbons, migrate from depth and escape at the seabed (Figure B- 4). The detection of seeps at the seabed is often a strong indicator that an active petroleum system is present and provides critical information about the hydrocarbon source, migration pathways, and maturity. In addition, seabed seeps often host unique biological communities and are indicators of excess pore fluid pressures in shallow sediments.

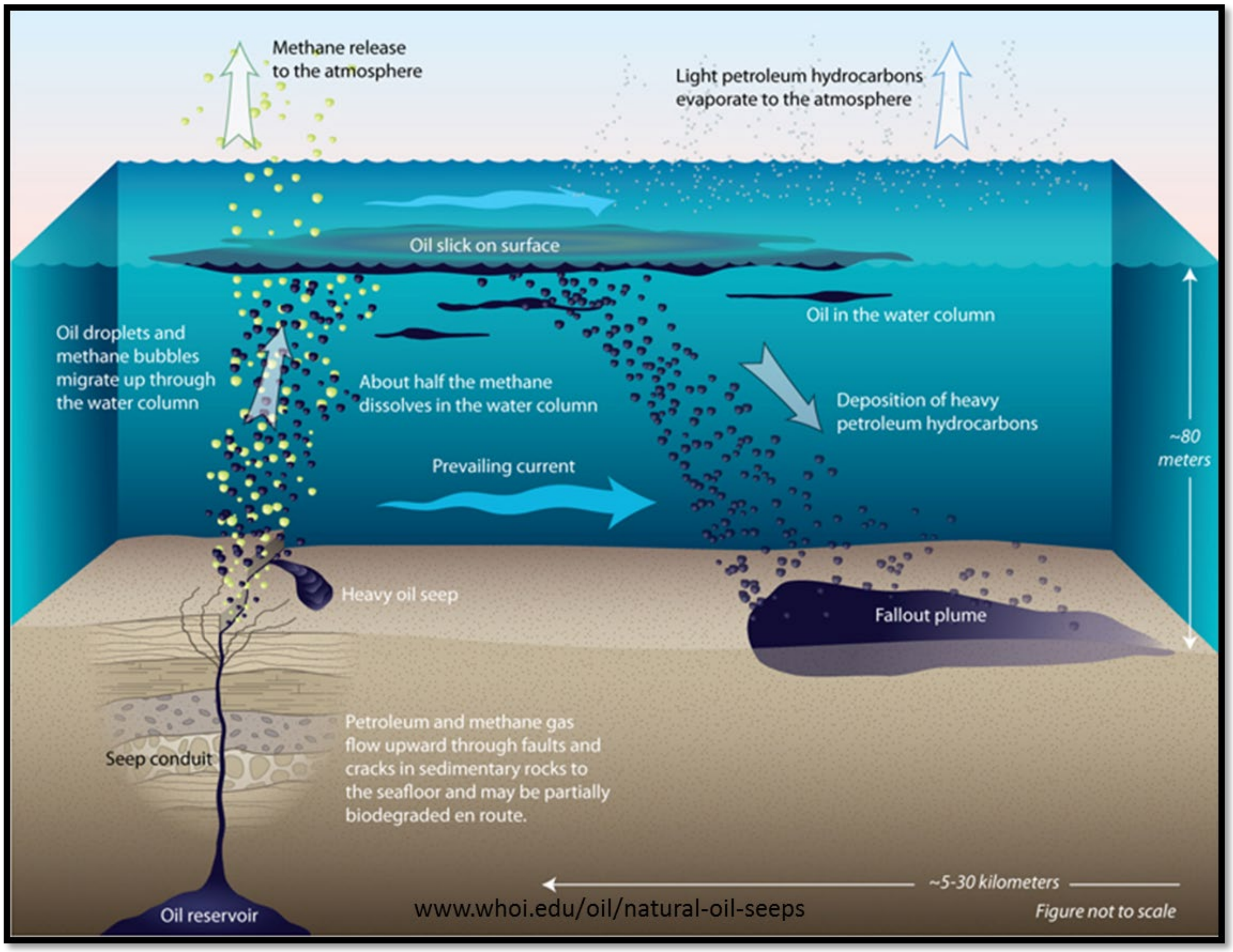

Figure B- 4: Cartoon depicting the components of a cold hydrocarbon seep.

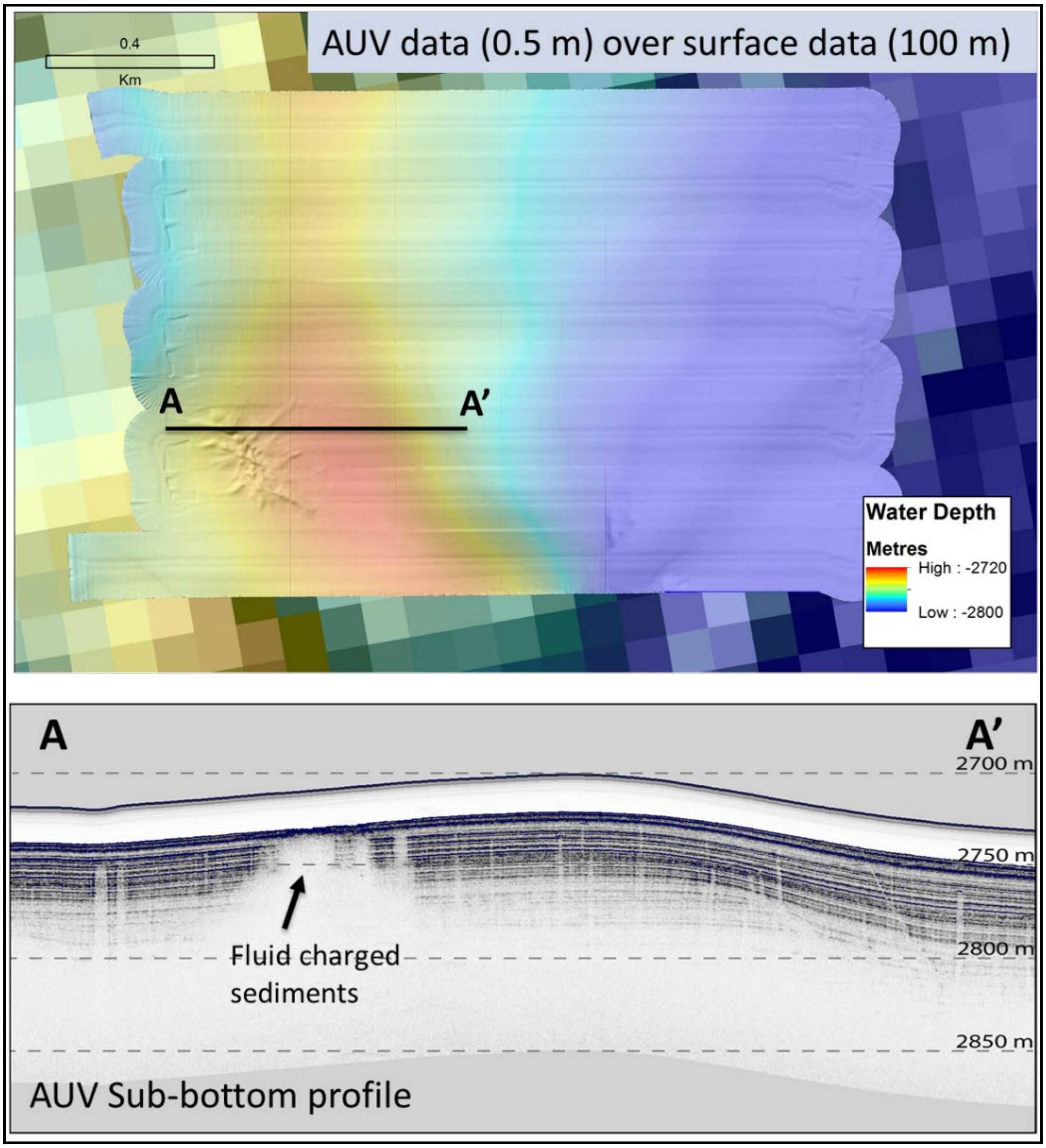

Figure B- 5: AUV swath bathymetry and sub-bottom profiler data at AUV site 2.

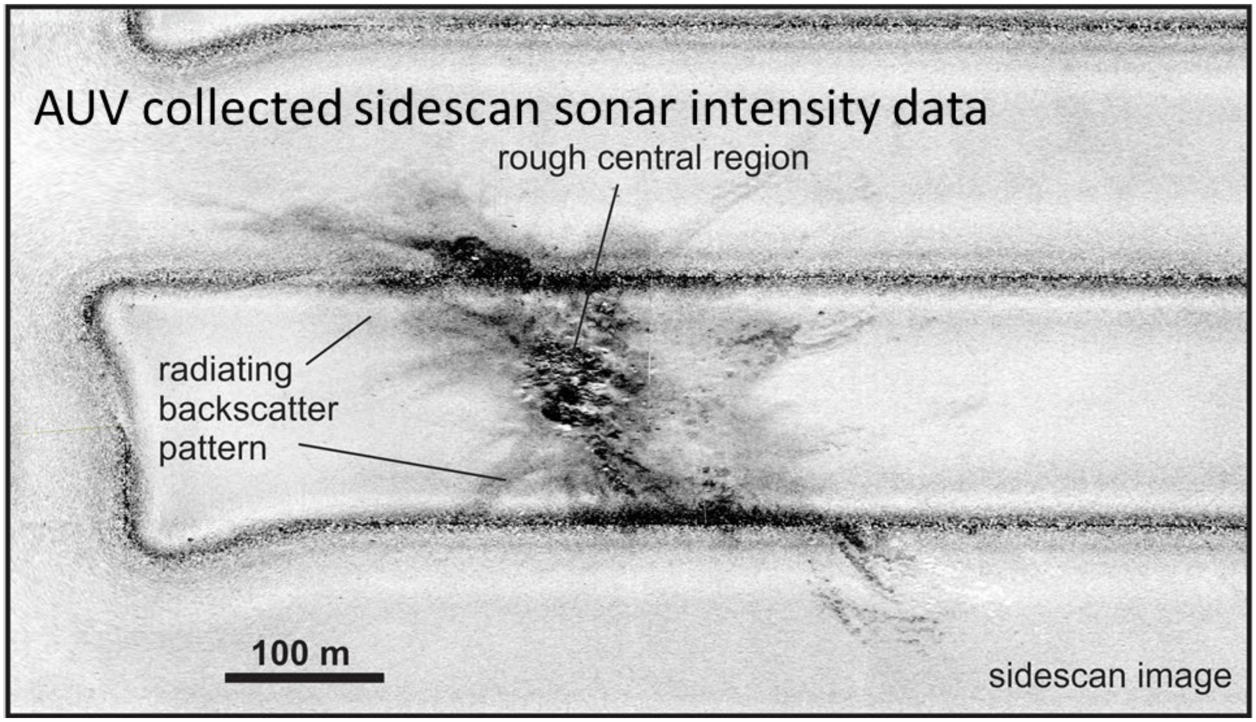

Figure B- 6: Planview image of AUV sidescan data at site 2.

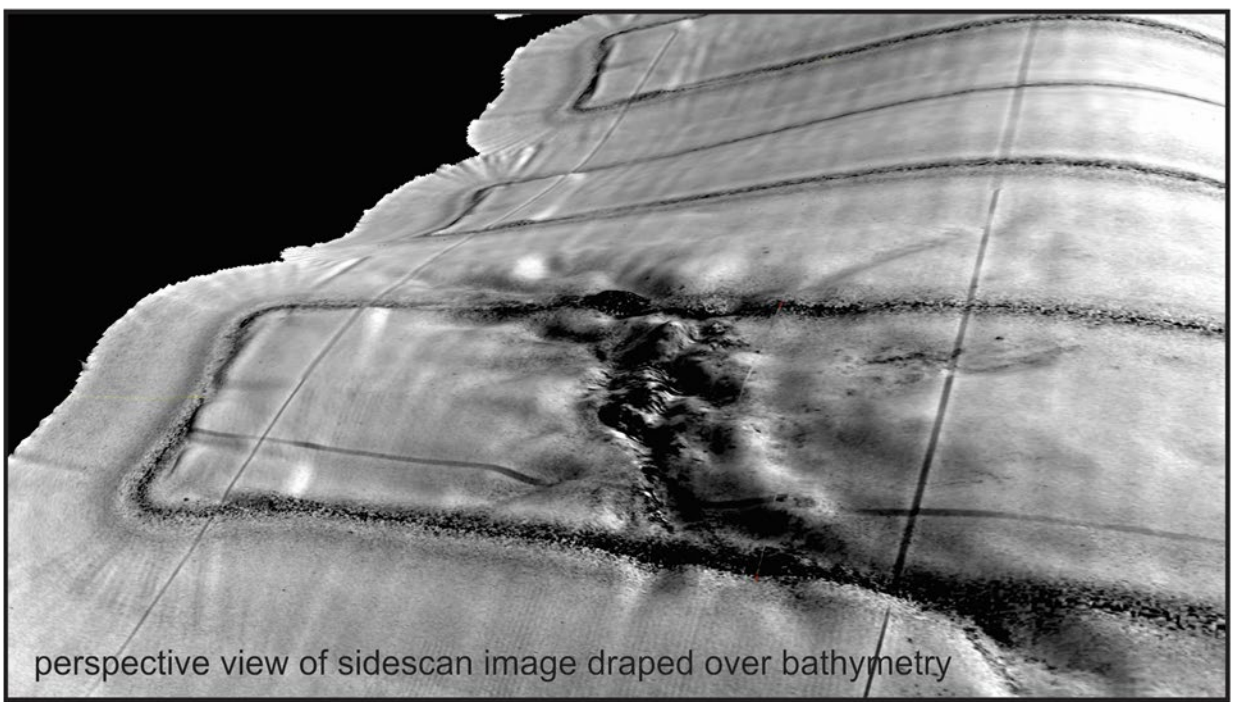

Figure B- 7: Perspective view of AUV sidescan draped over swath bathymetry.

AUV Site 3 – Extensive “Pockmarks” on Seabed in 2000 m water depth

At site 3, numerous pockmarks are associated with small submarine landslides seen on the AUV bathymetry. The surface-acquired data only shows hints of roughness.

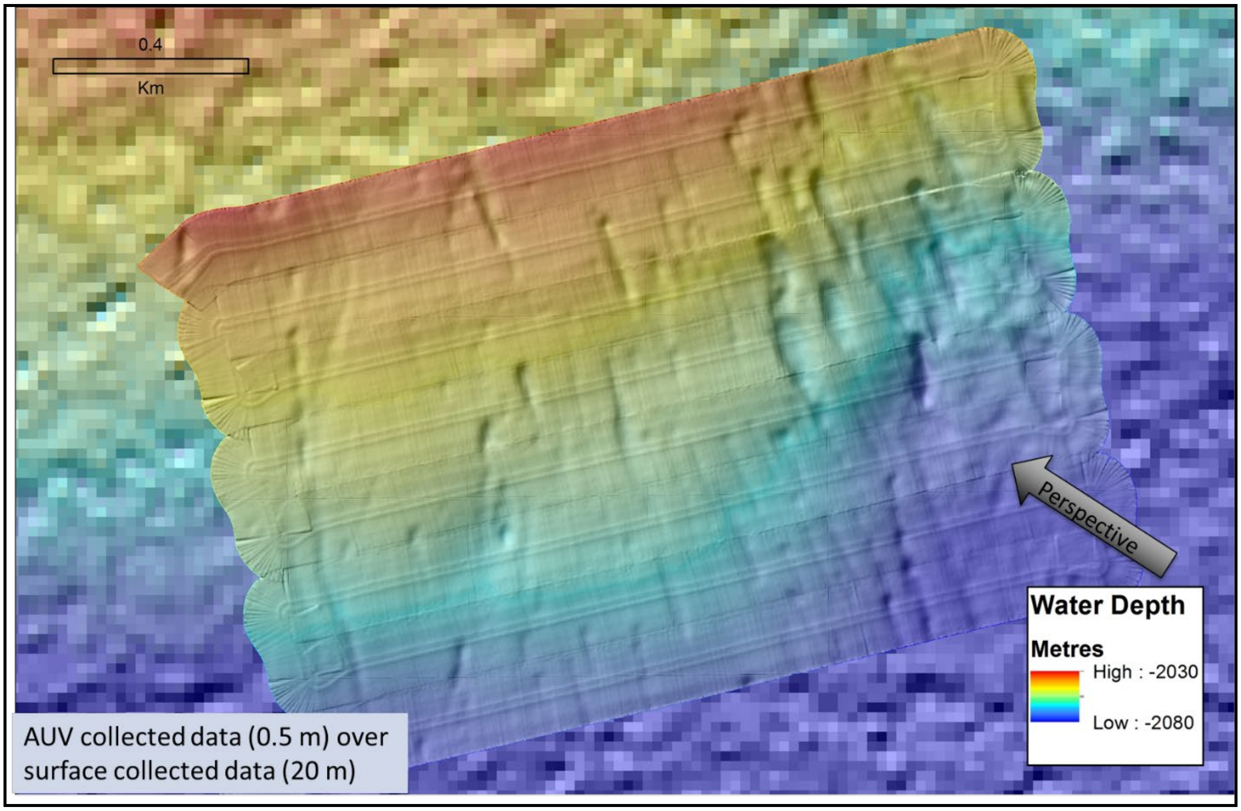

Figure B- 8: Planview of AUV swath at site 3.

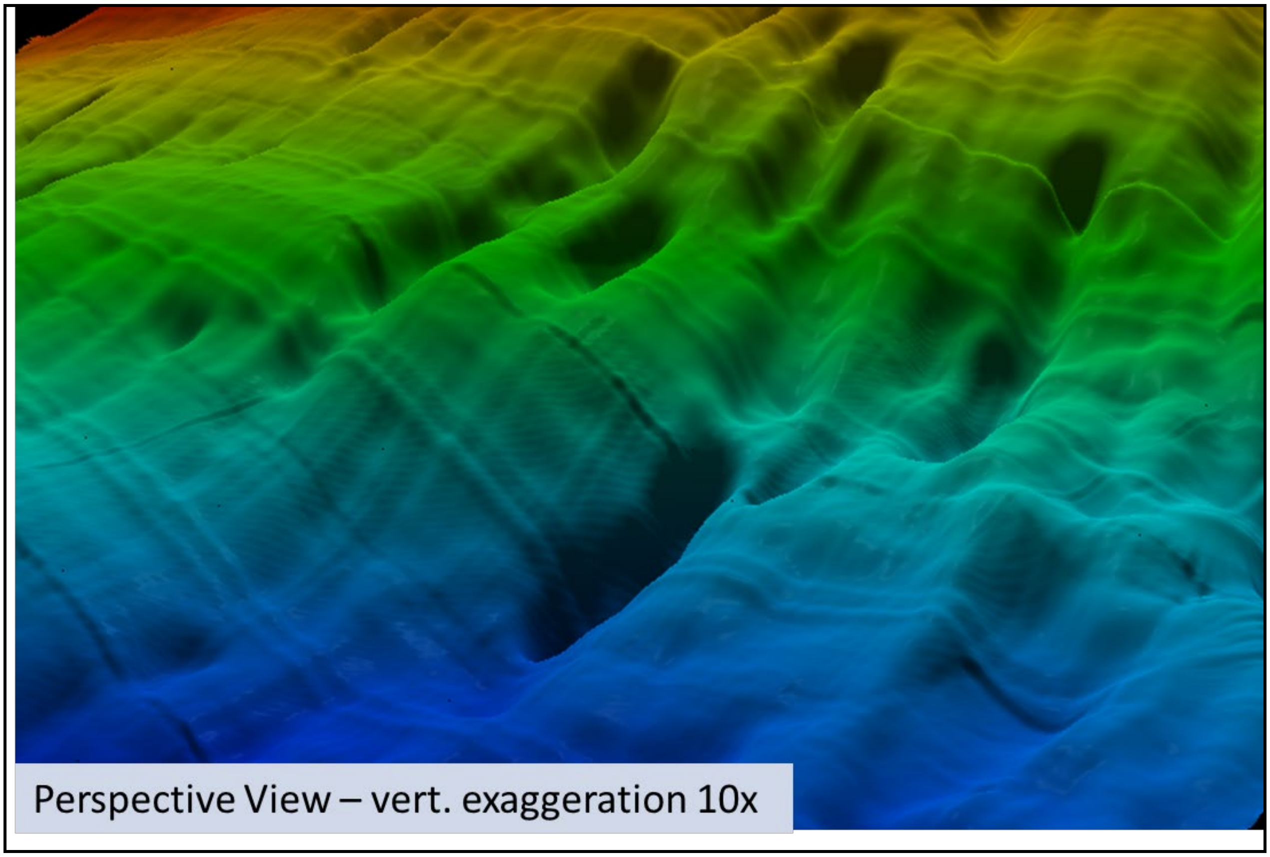

Figure B- 9: Perspective view of swath bathymetry at site 3.

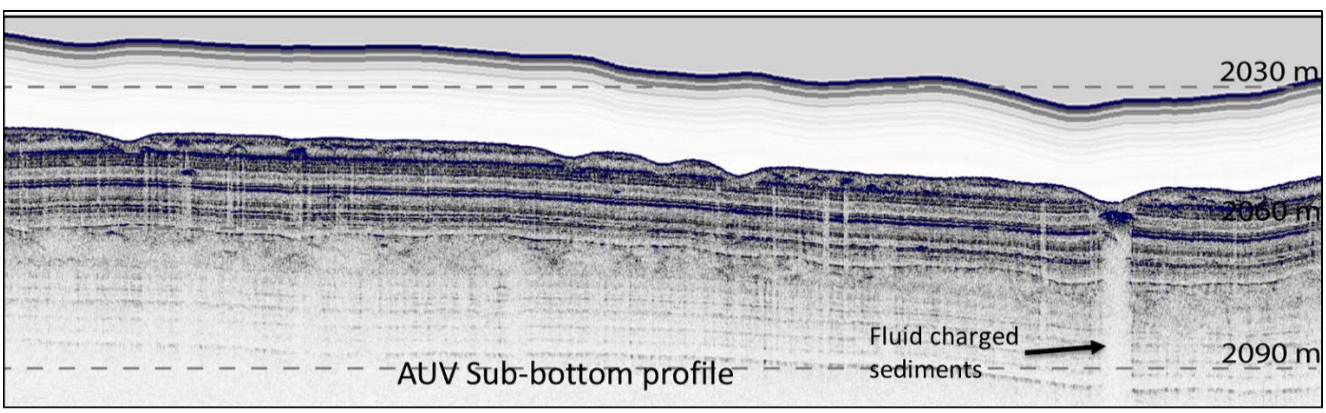

Figure B- 10: Example of AUV sub-bottom profiler data at site 3.